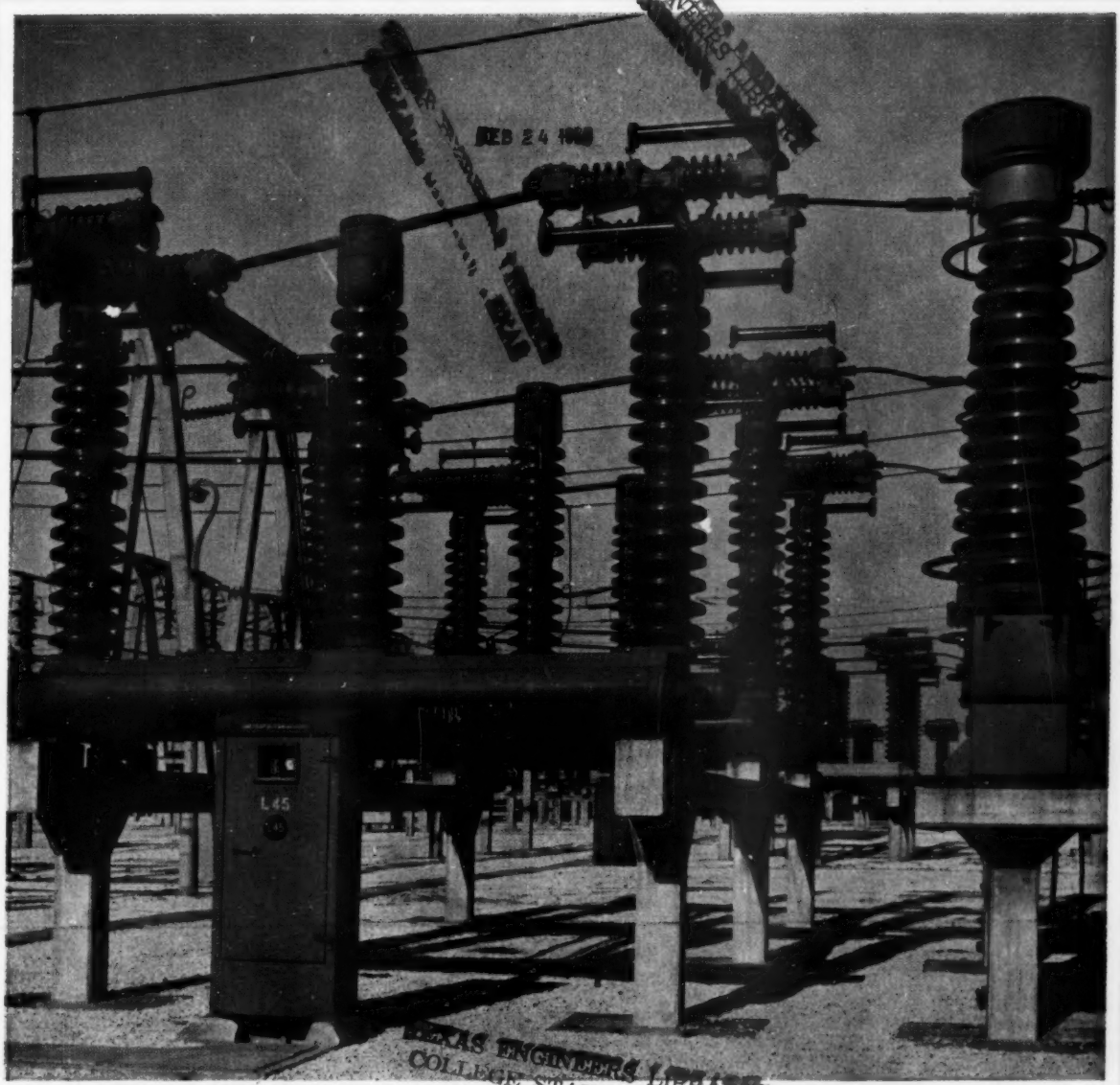


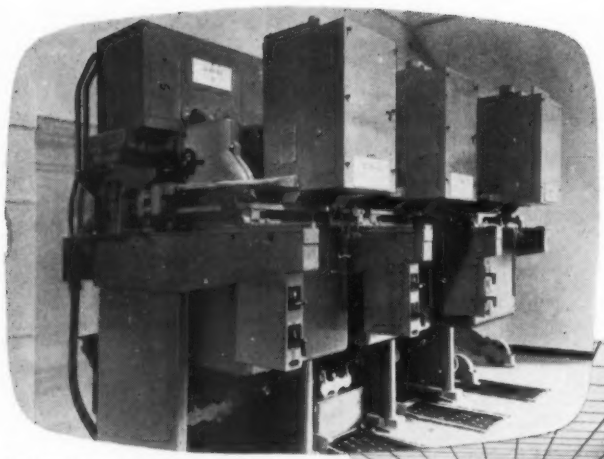
TEXAS ENGINEERS LIBRARY
COLLEGE STATION, TEXAS

TRAWSFYNYDD—Britain's latest nuclear power station, in North Wales, will incorporate a twelve-switch, double-busbar switching station, equipped with 275 kV, 7,500 MVA air-blast circuit-breakers, similar to those illustrated. They will be made at the Trafford Park Works of A.E.I. Switchgear Division.

Associated Electrical Industries Limited

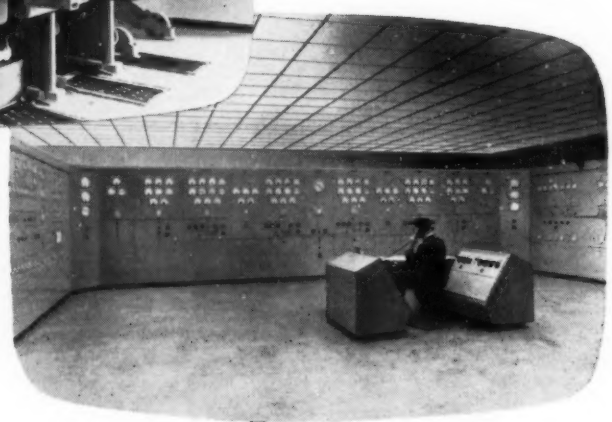
SWITCHGEAR DIVISION

Trafford Park, Manchester * Higher Openshaw, Manchester * Willesden, London



generator switchgear at Calder Hall

Photographs by courtesy of the U.K.A.E.A.



The generators at the Calder Hall Power-station of the Atomic Energy Authority are controlled by Reyrolle 11-kV 500-MVA and 750-MVA switchboards and their associated control-boards

Reyrolle equipment is also installed at:

Capenhurst,

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Dounreay,

Harwell,

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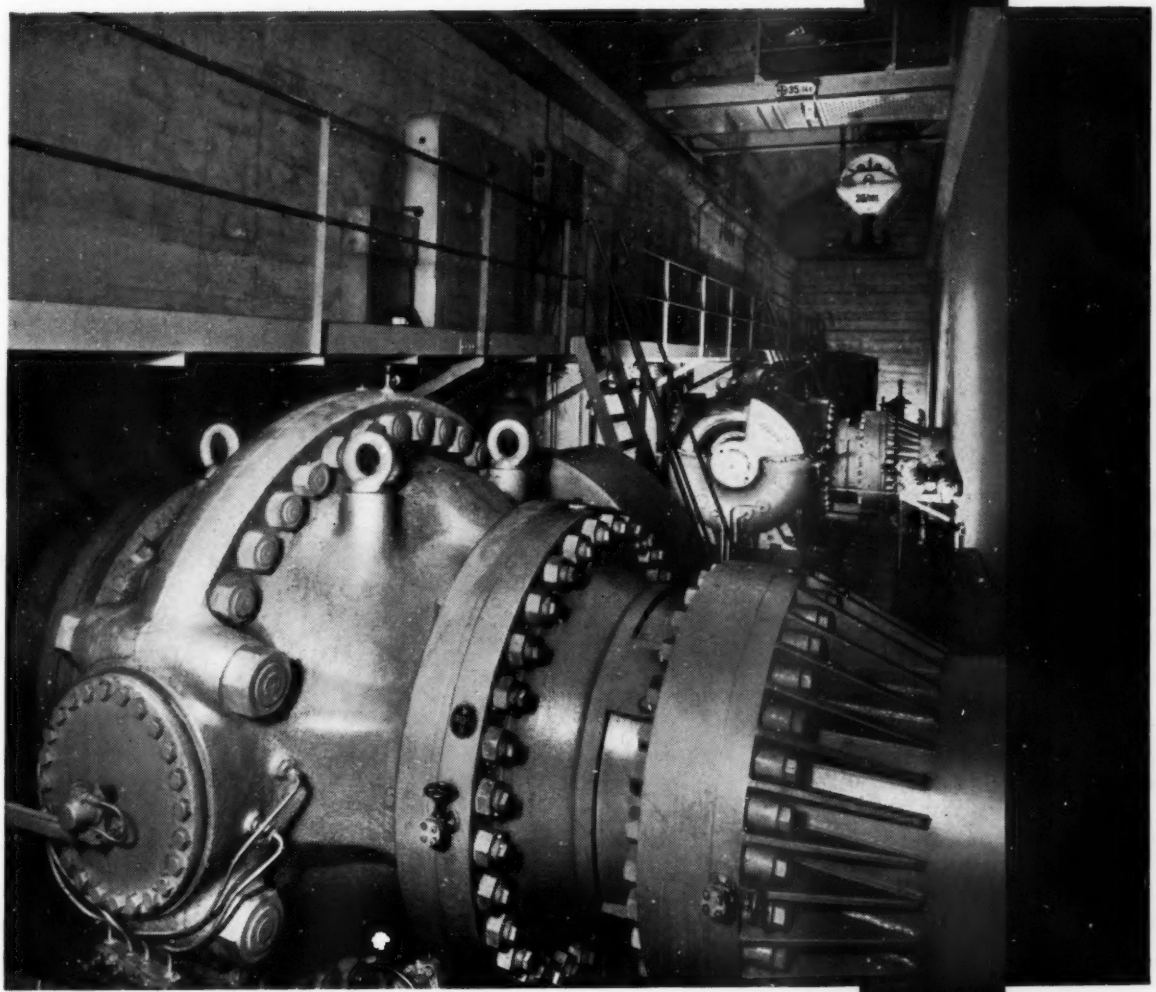
A. REYROLLE & COMPANY LIMITED, HEBBURN, COUNTY DURHAM, ENGLAND

Equipment for Hydro-Electric Power Stations



Valve chamber with rotary slide sphériques valves as turbine shut-off device in a swiss power station

Complete barrage installations; gates and hoisting equipment, gantry- and overhead travelling cranes, trash screen cleaning machinery; sluice gates; control valves for high pressure conduits; automatic safety organs for pipe lines; discharge regulating valves, rotary valves with rotary-piston servomotors, needle valves, butterfly valves, high pressure fittings, piping systems for oil and cooling water plant; funicular and aerial cableways for passenger and goods transport; building machinery for dam-building work.

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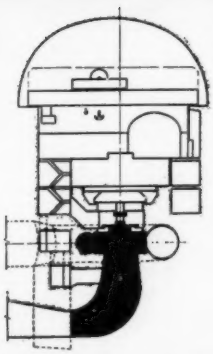
KARIBA—ON SITE—ON SCHEDULE

The Stay Ring for No. 1 Turbine at Kariba—shipped from England in May, 1958—is now in position. It is shown here installed in the vast underground power station, ready for the next major step, fabrication of the spiral casing.

This is the first of six Boving Turbines being installed at Kariba. Each is of 140,000 b.h.p.



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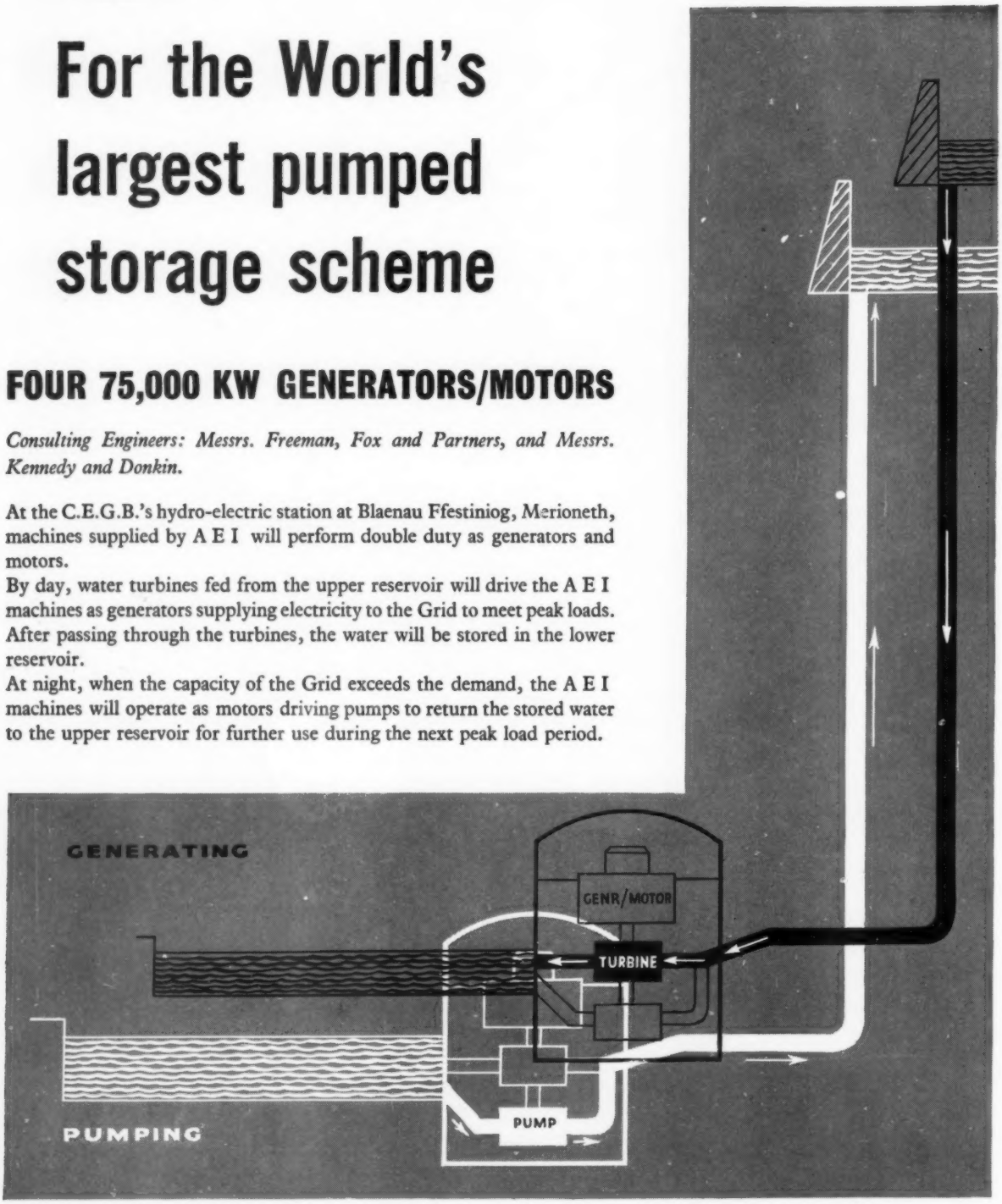
At the C.E.G.B.'s hydro-electric station at Blaenau Ffestiniog, Merioneth, machines supplied by A E I will perform double duty as generators and motors.
By day, water turbines fed from the upper reservoir will drive the A E I machines as generators supplying electricity to the Grid to meet peak loads. After passing through the turbines, the water will be stored in the lower reservoir.
At night, when the capacity of the Grid exceeds the demand, the A E I machines will operate as motors driving pumps to return the stored water to the upper reservoir for further use during the next peak load period.



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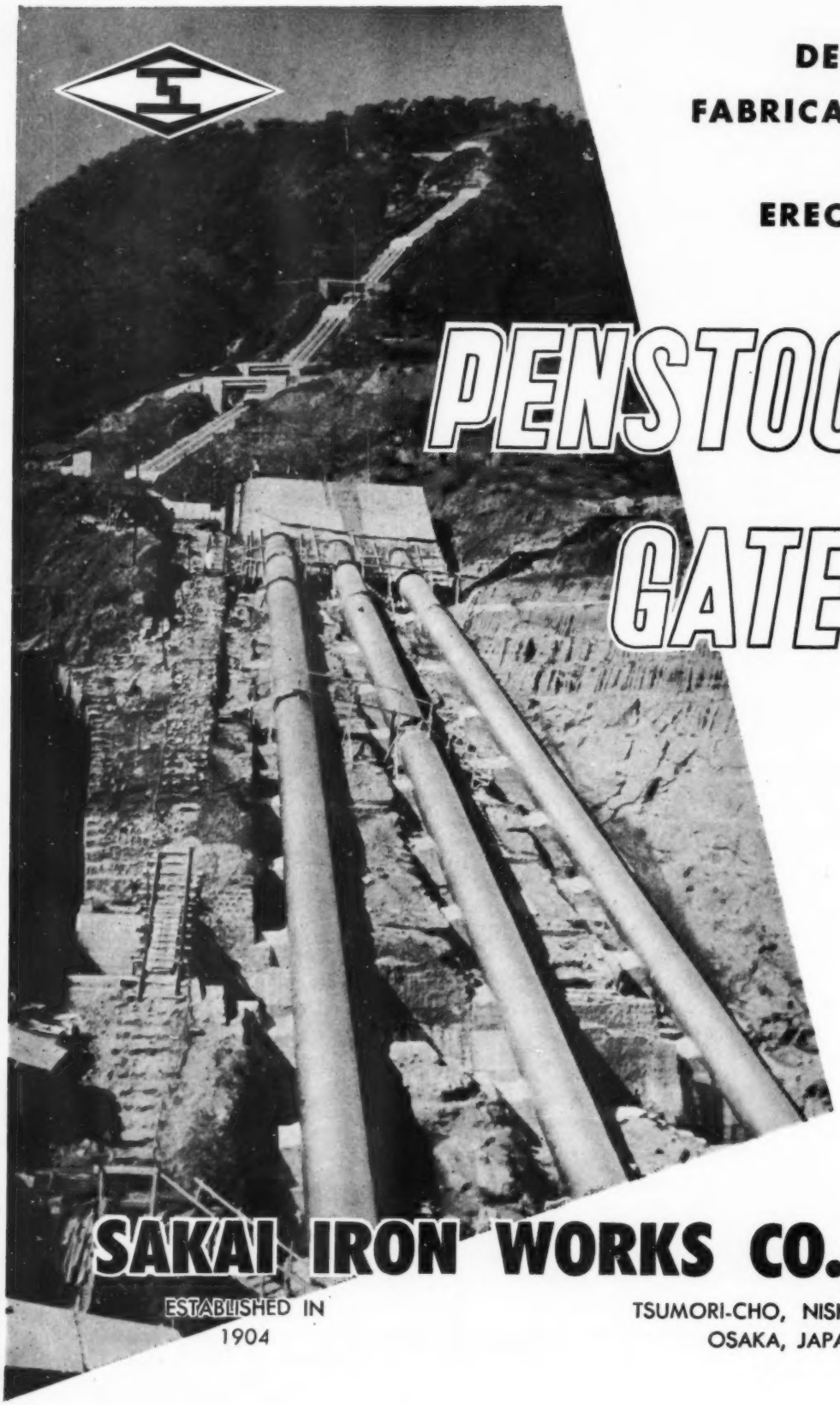

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FABRICATION
and
ERECTION
of

PENSTOCKS
and
GATES

SAKAI IRON WORKS CO., LTD.

ESTABLISHED IN
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TSUMORI-CHO, NISHINARI-KU,
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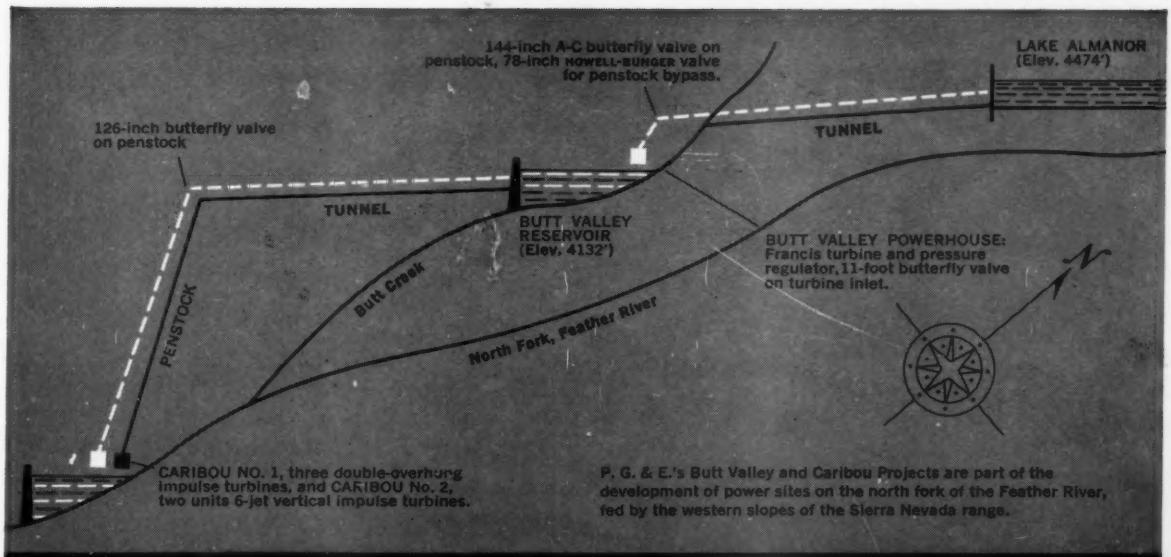
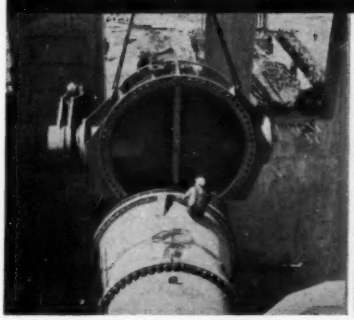
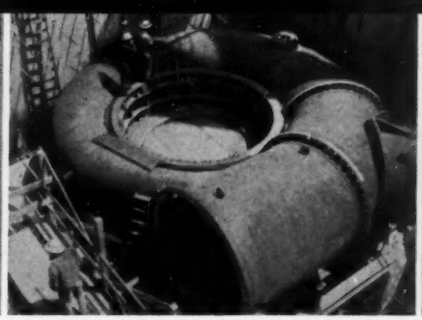

144-inch A-C butterfly valve on penstock, 78-inch HOWELL-BUNGER valve for penstock bypass.
LAKE ALMANOR (Elev. 4474')
126-inch butterfly valve on penstock
TUNNEL
TUNNEL
BUTT VALLEY RESERVOIR (Elev. 4132')
BUTT VALLEY POWERHOUSE: Francis turbine and pressure regulator, 11-foot butterfly valve on turbine inlet.
PENSTOCK
Butt Creek
North Fork, Feather River
CARIBOU NO. 1, three double-overhung impulse turbines, and CARIBOU No. 2, two units 6-jet vertical impulse turbines.
P. G. & E.'s Butt Valley and Caribou Projects are part of the development of power sites on the north fork of the Feather River, fed by the western slopes of the Sierra Nevada range.

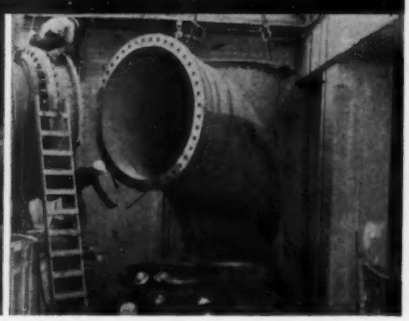
The 11-foot butterfly valve on the Butt Valley turbine inlet is shown being lowered into position.



Turbine spiral case in position at Butt Valley prior to the installation of the turbine runner.



Pressure regulator inlet elbow being positioned. Spiral case is at the left and energy absorber and discharge chamber below.



Allis-Chalmers Turbines, Pressure Regulator and Valves Installed at Butt Valley and Caribou Powerhouses, No. 1 and No. 2.

At Pacific Gas & Electric Company's new Butt Valley Powerhouse development, an Allis-Chalmers vertical Francis turbine with pressure regulator, two butterfly valves and one HOWELL-BUNGER valve are installed. This turbine is rated at 55,000 HP at 200 rpm under a 280-foot rated head.

A stalling-type pressure regulator, with provision for quick and simple conversion to synchronous bypass control, it's attached to the spiral case. Designed for a minimum opening time of 3 seconds, the pressure regulator is required because of the 5703-foot long penstock and the relatively remote location of the surge tank. An 11-foot A-C butterfly valve is located at the turbine inlet, while the other butterfly valve will be used as a penstock shutoff valve. The HOWELL-BUNGER valve serves as a penstock bypass.

Down stream from Butt Valley is Caribou No. 1 Powerhouse, with 3 Allis-Chalmers horizontal, double-overhung impulse units, 30,000 HP each, two units paralleled 1921, the third unit paralleled 1924, and Caribou No. 2 Powerhouse, completed along with Butt Valley in 1958. Caribou No. 2 has two Allis-Chalmers vertical, 6-jet impulse turbines, each rated 76,000 HP at 1110-foot head at 240 rpm. At each turbine inlet is a 54" rotary valve of latest Allis-Chalmers manufacture.

You can look to Allis-Chalmers for the latest in design, engineering and manufacturing of a complete line of hydraulic turbines and their accessories. For further information, contact your local Allis-Chalmers office or write Allis-Chalmers, Hydraulic Division, York, Pa.

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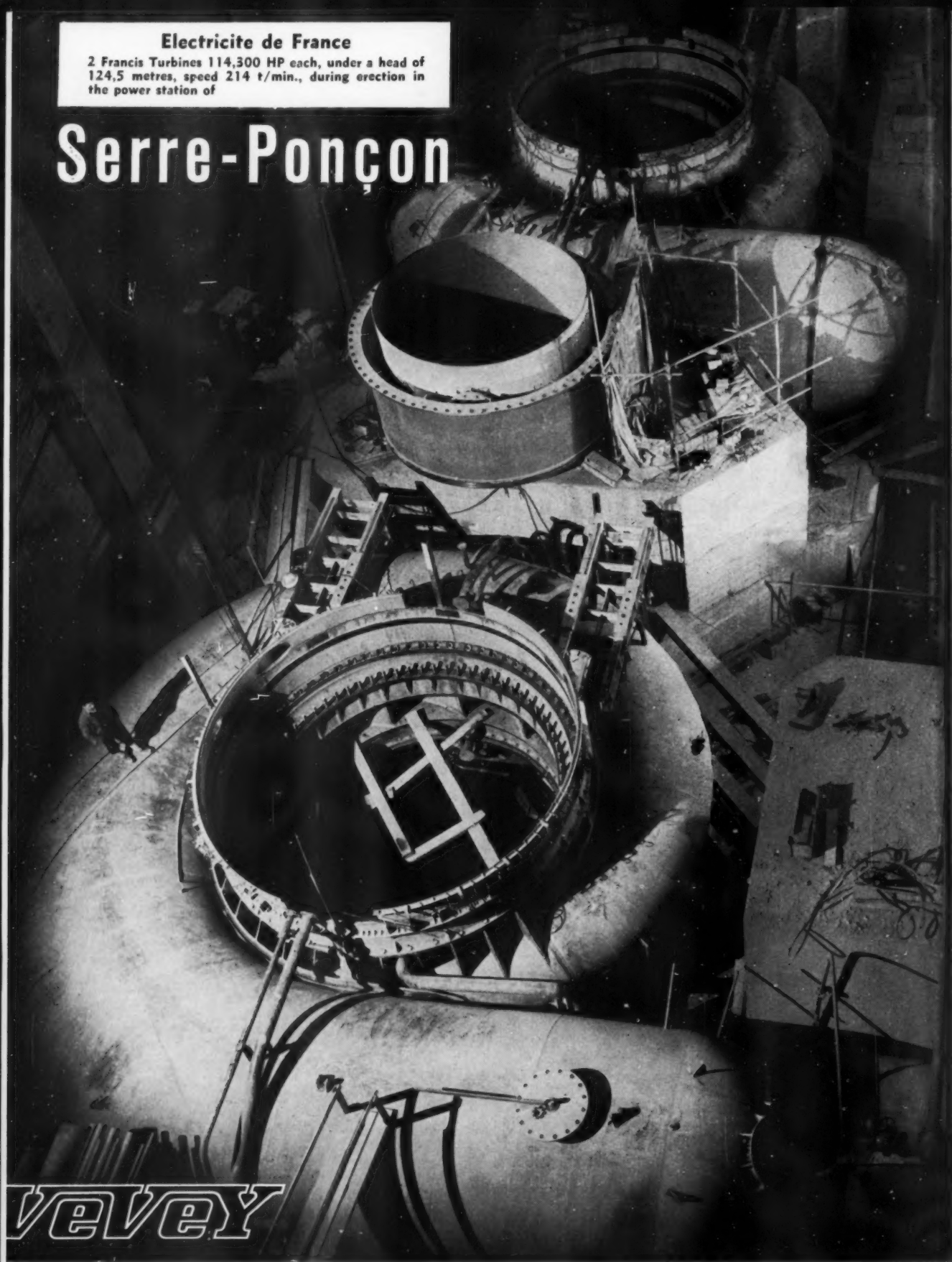
Electricite de France

2 Francis Turbines 114,300 HP each, under a head of 124,5 metres, speed 214 t/min., during erection in the power station of

Serre-Ponçon



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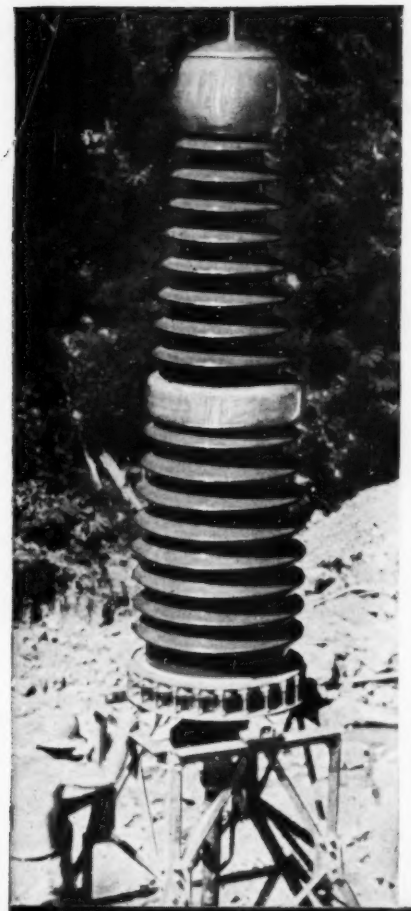


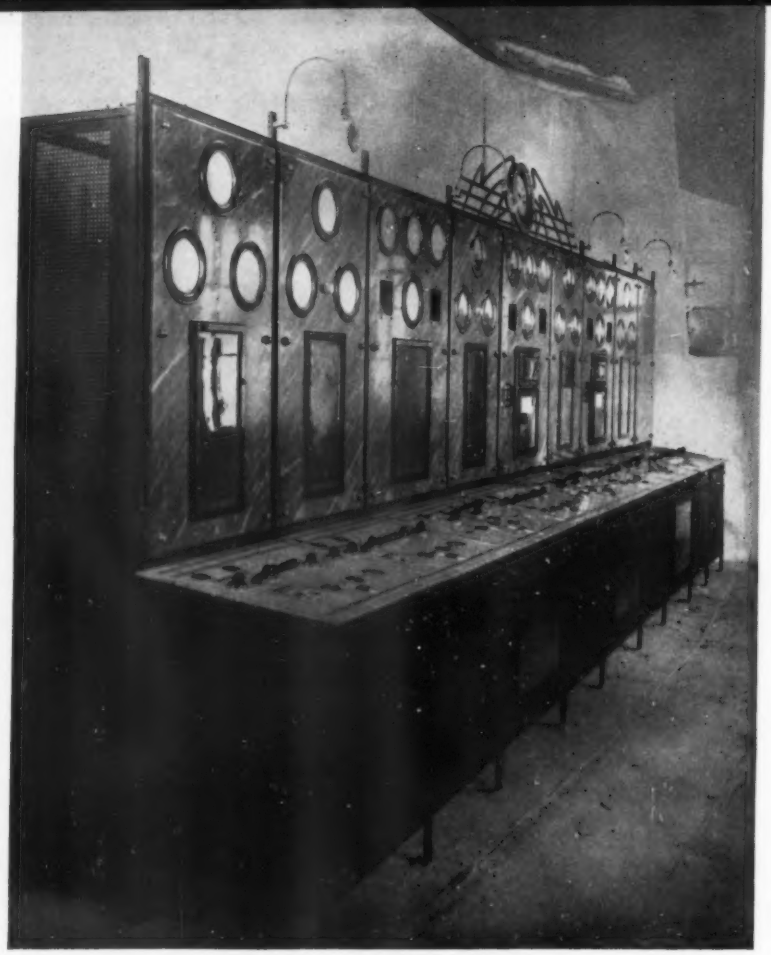
In the Snowy Mountains region of Australia, a great river, the Snowy, and its tributary, the Eucumbene, are being diverted from an easterly course to irrigate the western plains of New South Wales and Victoria. On its journey westward this water will fall more than 2,000ft.—a staggering power potential which, through a chain of hydro electric power stations, will eventually produce enough electricity to pay for the whole vast enterprise. For one of the first of these power stations, the T.1. on the River Tamut, a tributary of the Eucumbene, Pirelli-General have manufactured and installed the highest voltage oil-filled cables ever made in this country. Transmission of power at 330kV. 3 phase 194 M.V.A. (340 amperes phase) along a tunnelled route from an underground generating station to an outdoor switchyard some 1,600ft. distant *on the other side of the River Tamut,*

AUSTRALIAN SNOWY MOUNTAINS HYDRO-ELECTRIC AUTHORITY

FIRST with 330kv OIL-FILLED CABLES

proved a formidable undertaking, and the seven cables, all of which were installed in single lengths of 1,625ft. without intermediate joints, were carried on the bridge shown in the photograph. Pirelli-General are proud to announce that their contract to provide a vital link in this great Commonwealth enterprise has now been completed.

PIRELLI-GENERAL
CABLE WORKS LTD · SOUTHAMPTON



1919

SCARPA & MAGNANO established in April of 1919 as a small factory for the repair of electrical apparatus, expanded in the course of time its activity to include the construction of transformers and circuit breakers, thus always assuming major importance.

As main Contractor SCARPA & MAGNANO has projected and supplied in Italy and abroad important electric plants for production and transformation.

The exportation of the products of SCARPA & MAGNANO increased after the war and has steadily risen year by year gaining interest throughout the world.

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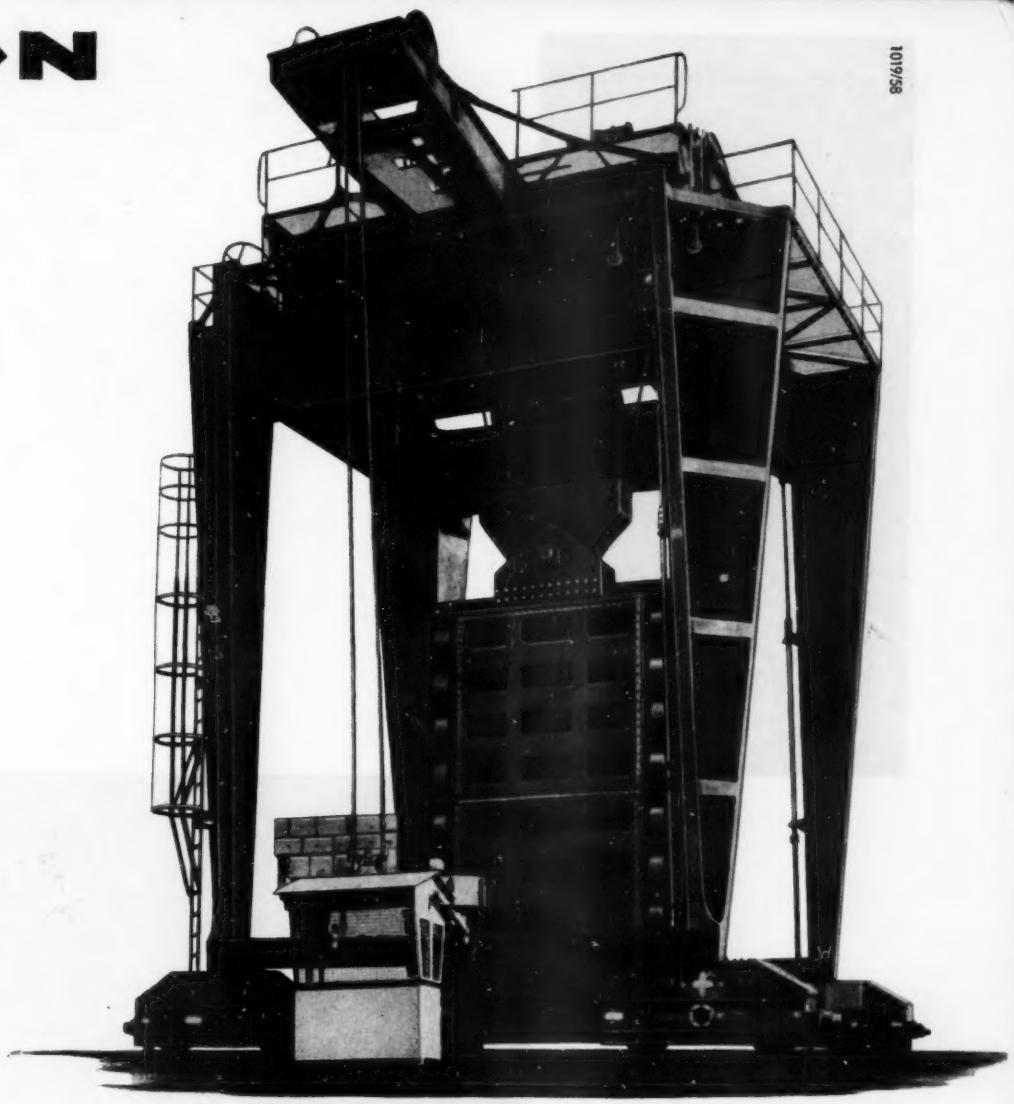

Dam crest crane of 160 tons capacity for moving the emergency gates of 3.05 x 6.59 m against a water head of 95 m, for the Dokan Dam, Iraq.

HYDRAULIC STRUCTURES

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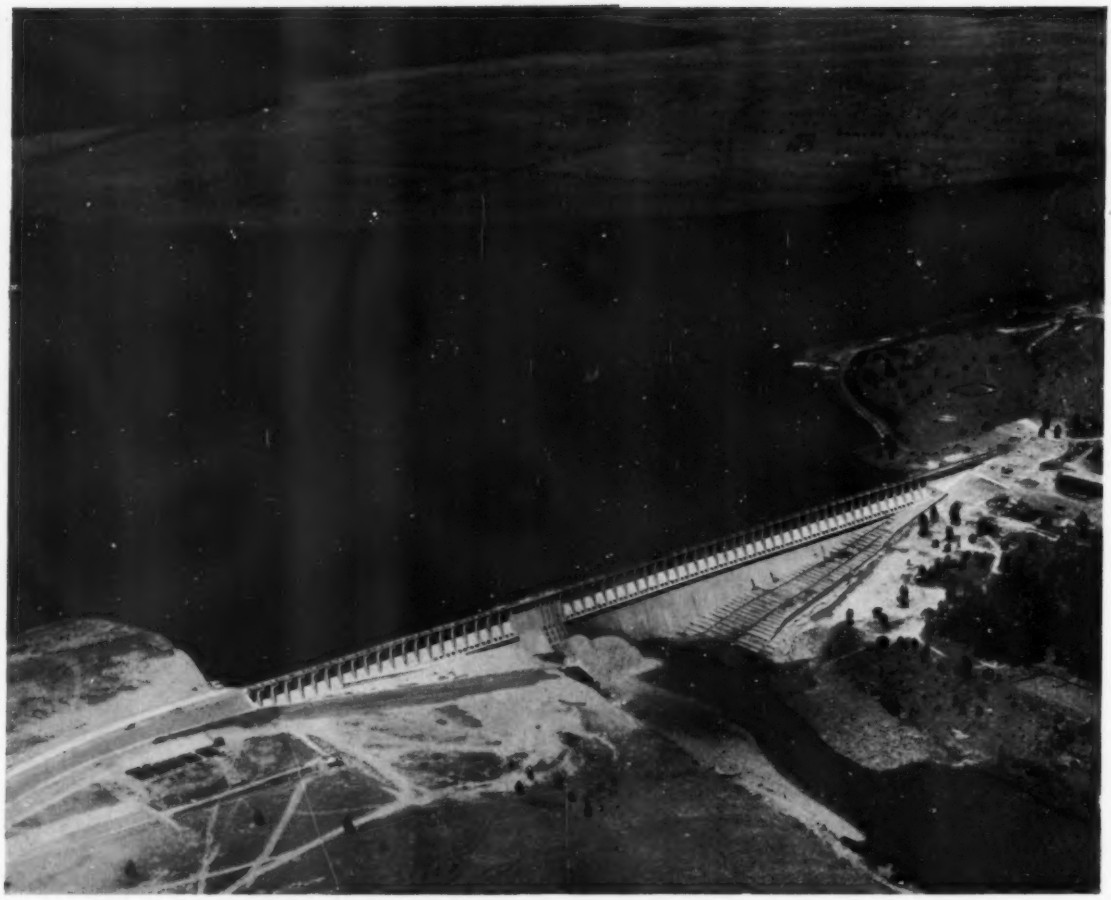
GUSTAVSBURG/HESSEN (GERMANY) REPRESENTATIVES IN ALL COUNTRIES



South Africa's Vaal-Dam is the largest man-made reservoir in the Southern Hemisphere.

Situated about 60 miles south of Johannesburg, the Vaal-Dam is almost half a mile wide. Its height was recently increased to a towering 180 feet.

Rheinstahl UNION Brückenbau AG. (formerly Dortmunder UNION Brückenbau-AG.) designed and manufactured the 78 spillway and emergency gates and supervised their installation into the dam.

RHEINSTAHL
UNION
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RHEINSTAHL UNION BRÜCKENBAU AG · DORTMUND/WEST GERMANY

Another 'first' for Ferranti

Ferranti Ltd. have received an order from the Central Electricity Generating Board through the Northern Project Group for the largest Transformers ever ordered from a manufacturer in this country by a British customer. The placing of this order demonstrates Ferranti's leading position in the Transformer industry. The contract is for two 310,000 kVA, 3 phase, 50 cycle double-wound Transformers for installation at Blyth 'B' Power Station, Northumberland, to step up the Generator voltage to 295 kV and to provide a direct connection to the Super Grid. The units are water-cooled and incorporate all the latest research and developments; they will be equipped with Ferranti Resistor Type On-Load Tap Change Gear.

The Consulting Engineers are Merz & McLellan.

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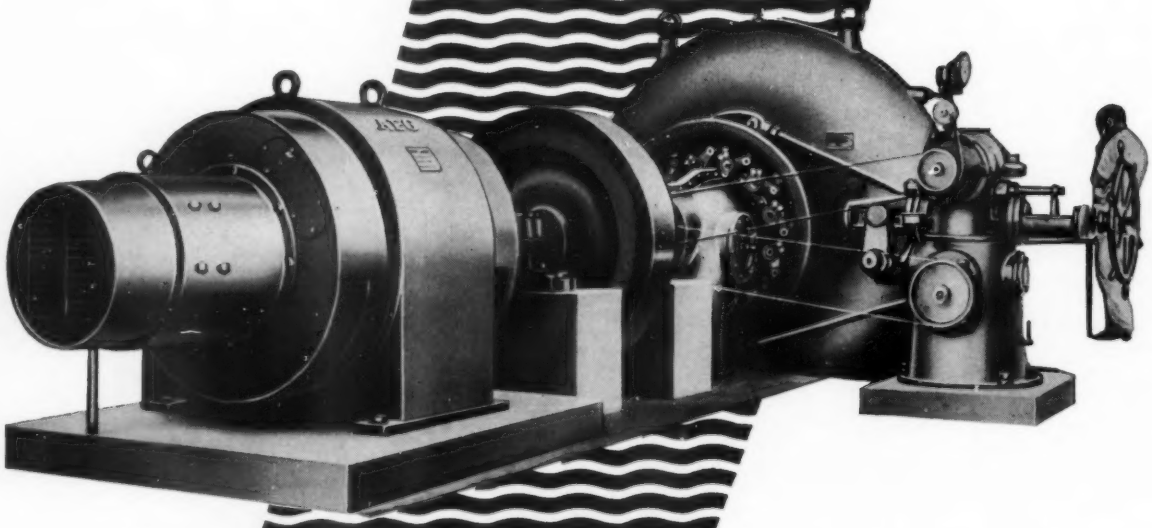

Here is a small generating set installed in Central America to feed additional power into an urban system.
AEG Alternator
523 kVA output, at 400 V A. C., direct-coupled to a Francis turbine

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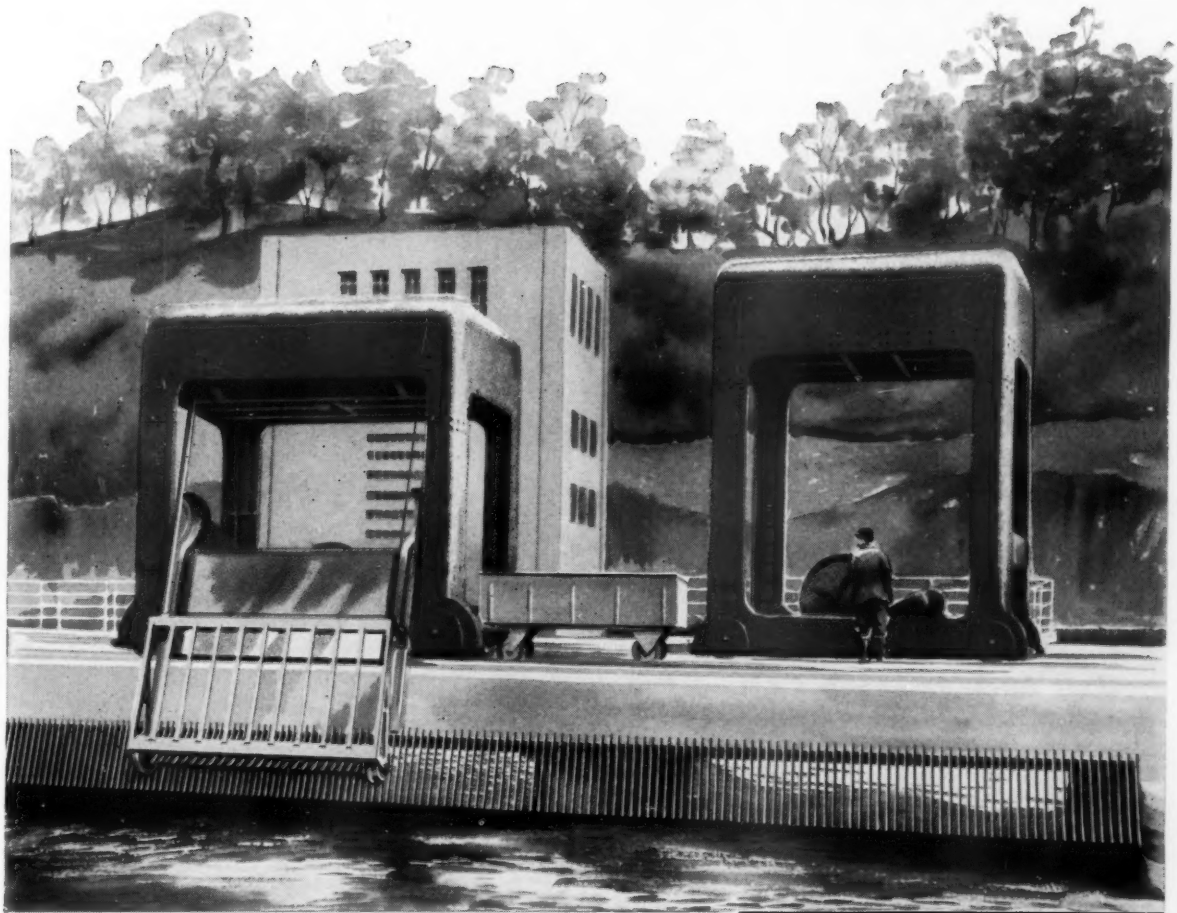

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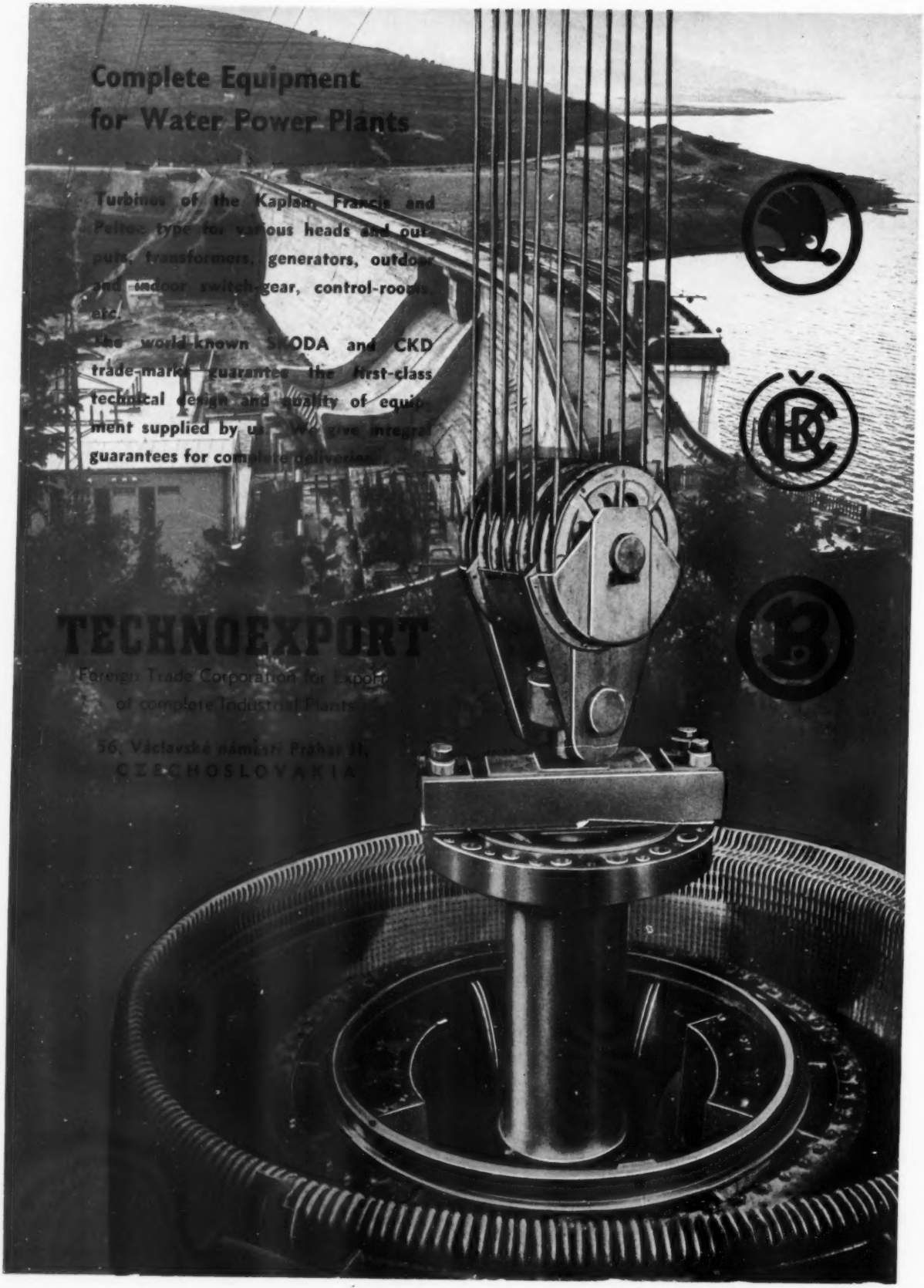
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U.P. Government
Madras Government
Mysore Government
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Kunda, Madura, Mettur Dam, Moyar, Papanasam and many other substations on the Madras Grid.

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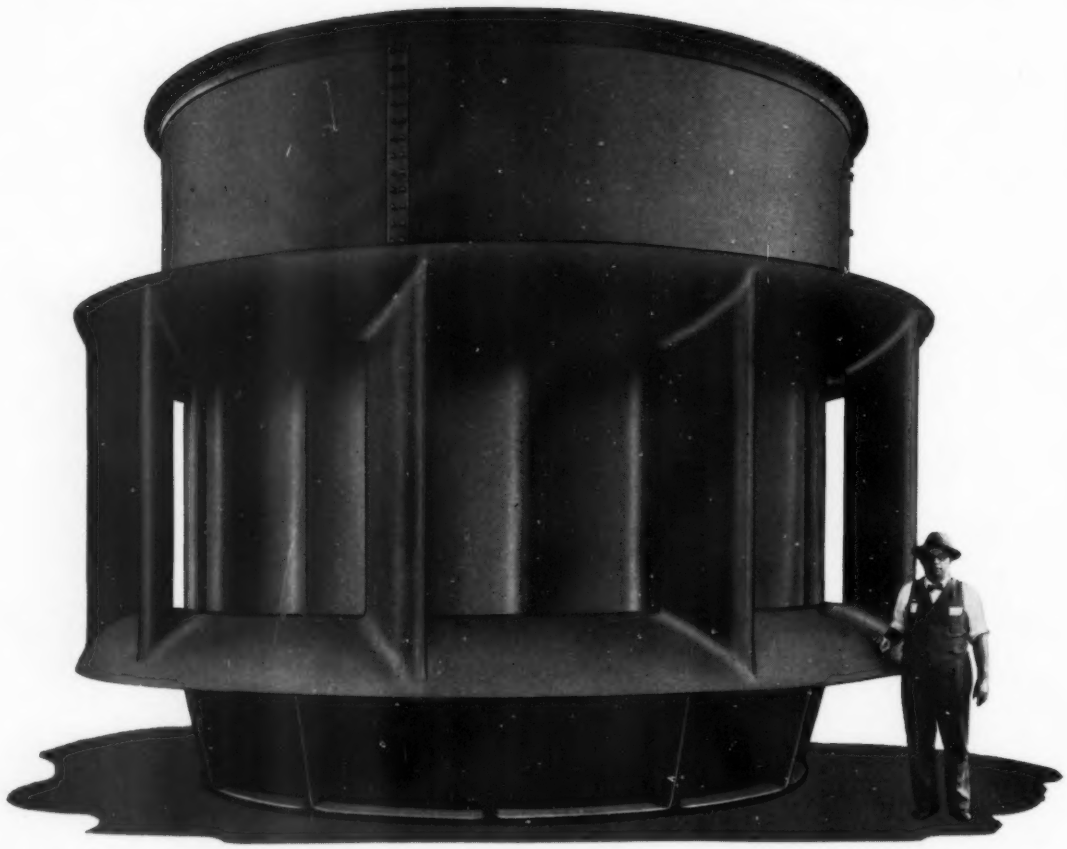

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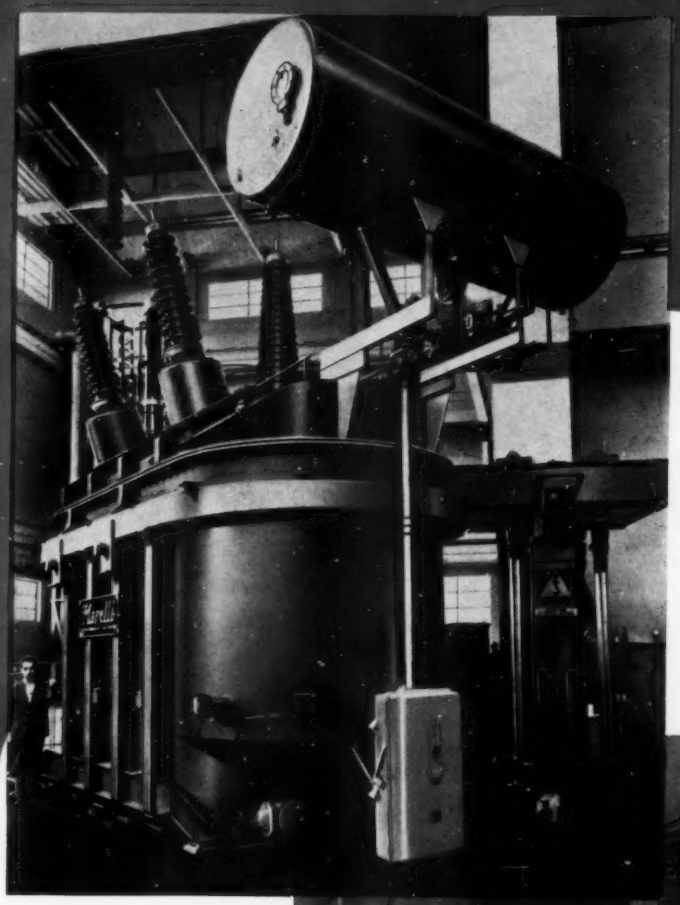
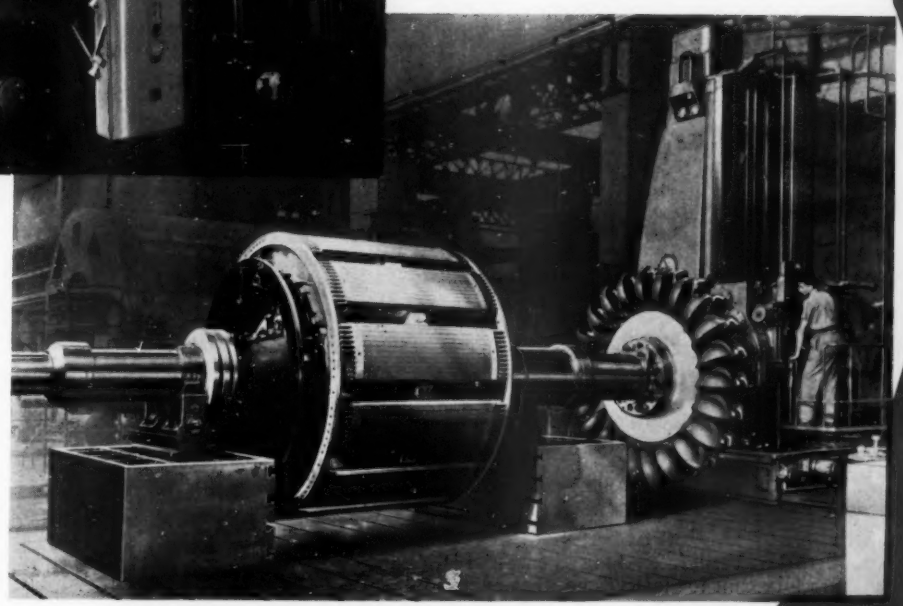


SINGLE PHASE TRANSFORMER for three phase bank 150/150/50 MVA —220/120/10·5 kV—50 cycles 4 units for NIKOLA TESLA substation, Yugoslavia



Shaft for 25 MVA horizontal type Alternator coupled to Pelton Wheel gauging the coupling bolt holes

2 units manufactured for OESTERREICHISCHE DRAUKRAFTWERKE Kollnitz Reisseck power station

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Exclusive to SPEEDLINE drills, DUAL VALVES supply air at exactly the right moment — on both up and down strokes. Operating independently, DUAL

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SPEEDLINE L37

A 35 lb. class tool with power-to-spare for many applications. On quarry, mine and building site, the L.37 makes light work of it.

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A husky 50 lb. class drill with the performance of many conventional heavyweights, the L.47 drills up to 16 ft. in favourable conditions. For wet or dry drilling.

THE JAL47 AIRLEG DRILL

for maximum footage in mining and tunnelling. One-hand feed control, perfect balance, high penetration speeds with low maintenance costs . . . the Air Leg Rock Drill removes strain from the operator — reduces drilling time, a controlling factor in maintaining good cycle times.

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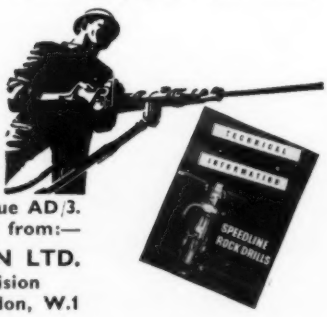

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JOY SULLIVAN LTD.
Air Power Division
7 Harley St., London, W.1

1947 TO 1958

EXTRACTS FROM OUR REFERENCE LIST

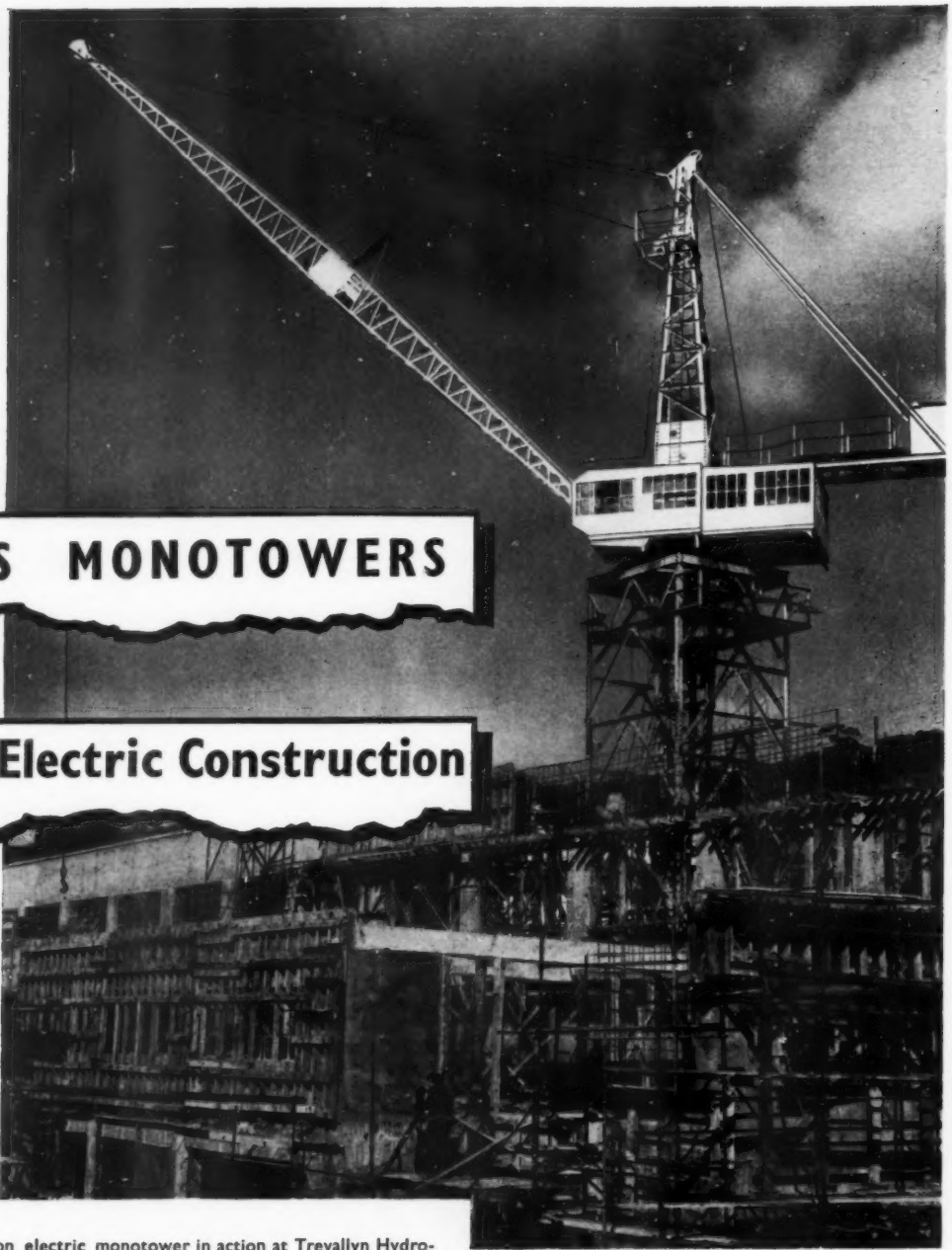
44,948 TONS OF PENSTOCKS

DESIGNED · SUPPLIED · ERECTED

Serial No.	Name of Plant and Country		Head in m	Weight in tons	Diameters in m/m	Length in m	Plate thickness in m/m	No. lines	When ordered
261	Grønsdal	Norway	177	302	2200–1900	255	12–23	1	1947
262	Dale III	„	311	737	2000–1400	700	12–35	1	„
263	Grytten	„	424	374	900–800	1070	8–22	1	„
264	Maudal II	„	370	889	1650–1450	900	12–30	1	„
268	Skjerka II	„	340	1502	2100–1650	1240	22	1	„
272	Sand	„	320	181	500–450	1650	7–10	1	„
273	Søre Sunnmøre	„	377	235	1100–850	682	9–23	1	„
275	Glomfjord (Flow Lines)	„	—	368	550	3037	7	1	„
277	Pykara IV	India	936	3000	1067–991	3025	12–49	1	„
283	Lund	Norway	251	190	700–550	1112	8–10	1	1948
284	Vadheim II	„	313	222	1050–850	676	9–17	1	„
286	Festa	„	210	194	1300–1200	407	10–14	1	„
288	Kåven	„	117	180	1600–1500	360	10–12	1	„
290	Vinstra I	„	447	1020	2400–2200	387	14	1	1949
291	Tafjord	„	400	400	1750	608	8–14	1	„
292	Åbjøra	„	439	739	2300–900	666	12–35	1	„
293	Poringalkuthu	India	181	2000	2590–1320	887	11–30	3	„
294	Machkund	„	260	1450	1600–1450	500	11–32	3	„
298	Sueva I	Colombia	233	88	800–100	514	5–10	1	1951
299	Sueva II	„	187	135	1200–1000	509	6–12	1	„
302	Trevallyn	Tasmania	163	470	4420–1727	152	24	1	1952
304	Aura II-C	Norway	295	396	2200	416	12–44	1	„
305	Aura II-D	„	744	1112	1600	1212	12–44	1	„
306	Røssåga	„	247	1237	3400–3000	398	13–26	2	1953
309	Nore	„	368	337	1800–1300	475	12–34	1	1954
313	Mocorongo	Colombia	331	657	2000–1736	1015	9–21	1	„
316	Hardeland	Norway	322	272	1300–1000	879	8–15	1	1955
319	Poringalkutha	India	181	480	2590–1320	887	11–30	1	„
320	Hjartdøla	Norway	587	1061	2600–1500	1145	10–49	1	1956
321	Machkund 2nd Stage	India	260	1500	1600–1450	500	11–32	3	„
322	Bhakra (Bulk Heads)	„	—	60	4450	—	17,5	–	„
323	Kaldåga	Norway	566	789	1300–1000	1803	8–23	1	„
329	Sande	„	90	225	600	3000	5	1	„
332	Gjuva	„	390	206	1200–800	875	8–14	1	„
334	Innset	„	187	400	3200–2000	253	14–22	1	1957
337	Neriamangalam	India	224	900	3353–1600	1359	12–17	1	1958
338	Kiewa I	Australia	—	5	1912–864	—	20	–	„
339	Fortun II	Norway	873	112	1600–1300	75	30–61	1	„
340	Vrenga	„	379	440	1300–900	1568	8–11	1	„
341	Tyin II	„	1009	1485	1600–1200	1857	10–47	1	„

FERRUM MONTAGE A/S

OSLO · NORWAY



BUTTERS MONOTOWERS

in Hydro-Electric Construction

This crane is a 5 ton electric monotower in action at Trevallyn Hydro-Electric Power Station near Launceston, Tasmania. It has a 100 ft. jib, 80 ft. tower, and handles 5 tons at 75 ft. and 1¼ tons at 100 ft. radius. The ideal crane for erection of dams and high buildings generally, with all the dependability of the Butters product.

BUTTERS BROS. & CO. LTD.

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Telephone: IBROX 1141 (6 lines) *Telegrams: "BUTTERS, GLASGOW."*

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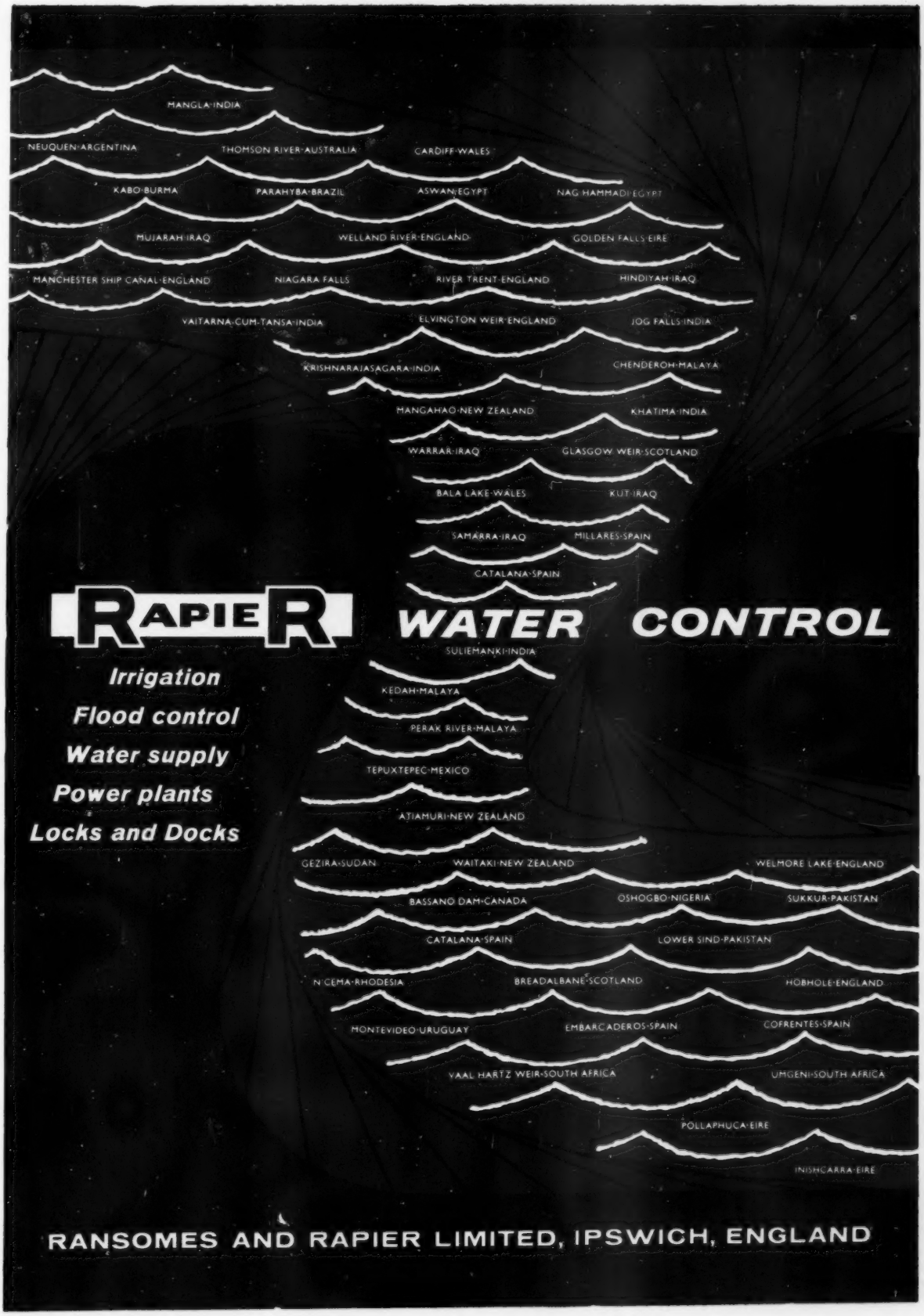
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VÖEST

Hydraulic Turbines, Spherical and Butterfly Valves

Licensed by Baldwin-Lima-Hamilton Corp.
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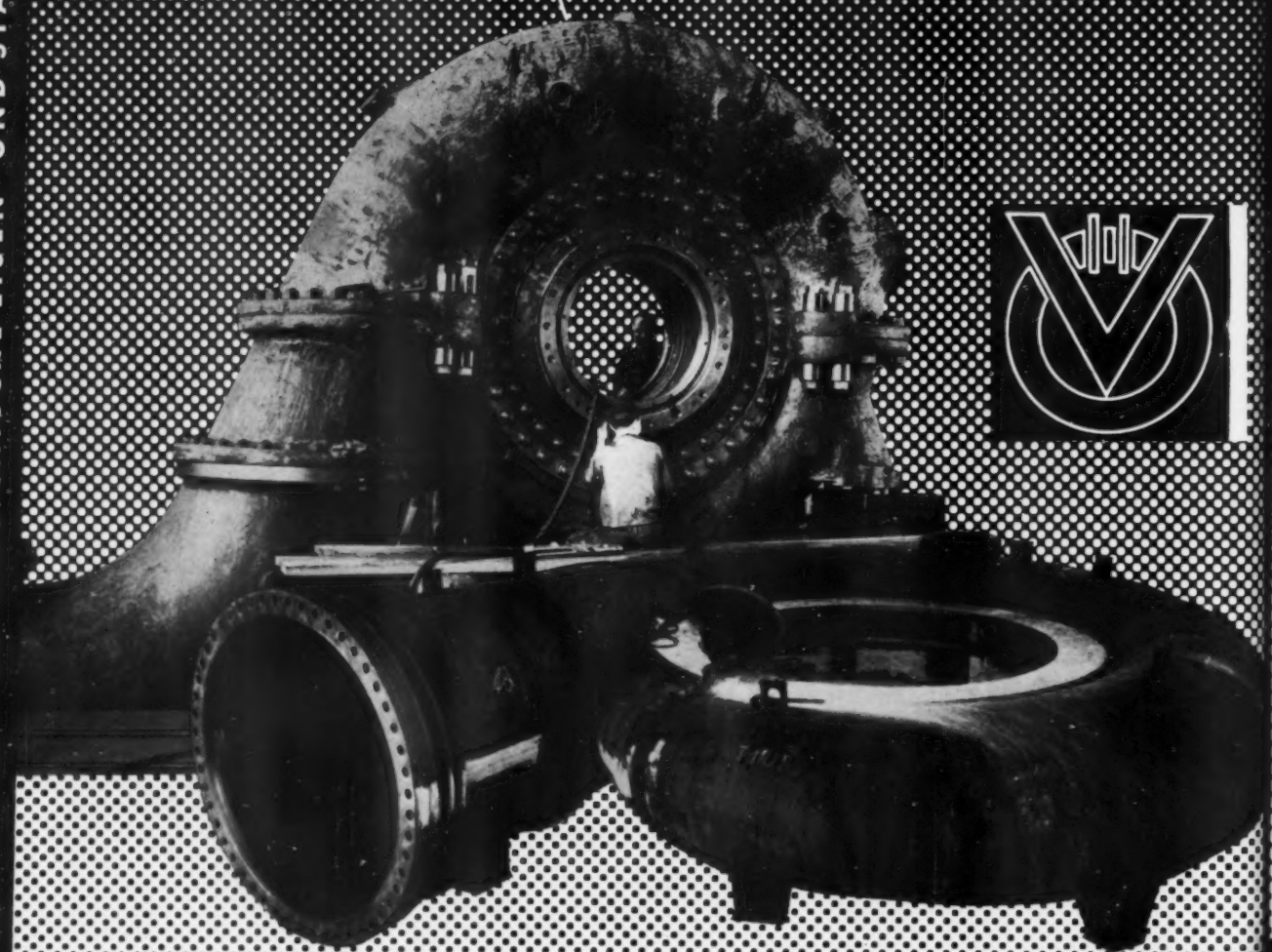
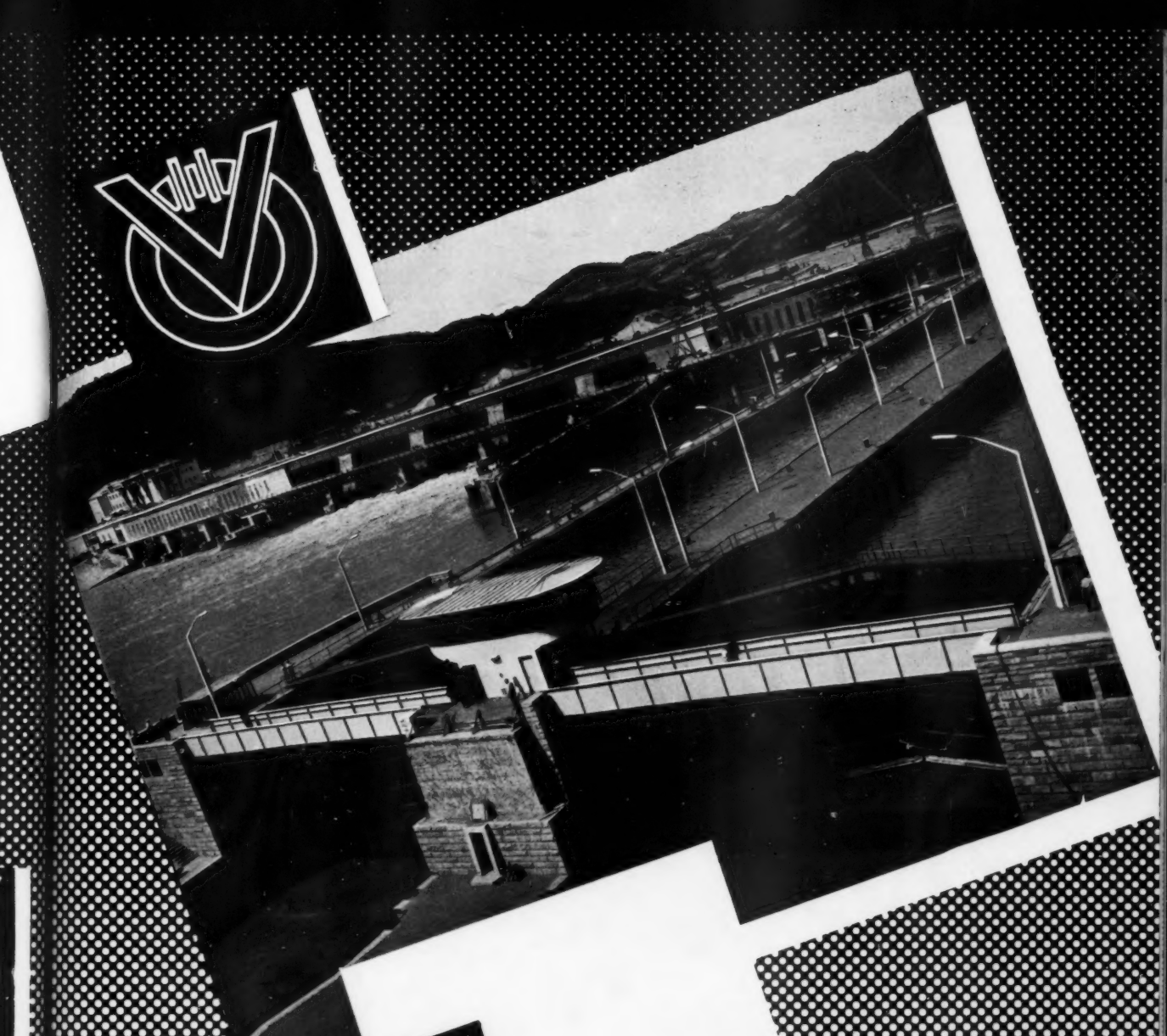


VÖEST-ALPINE MASCHINENTECHNISCHE EISEN- UND STAHLWERKE, LINZ-DONAU, AUSTRIA



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HYDRAULIC STEEL CONSTRUCTION

Steel structures for weirs and loch gates of every type, including the required auxiliary equipment; mechanical and hydraulic drives hereto sprocket chains; trash rake cleaning machines; weir cranes.

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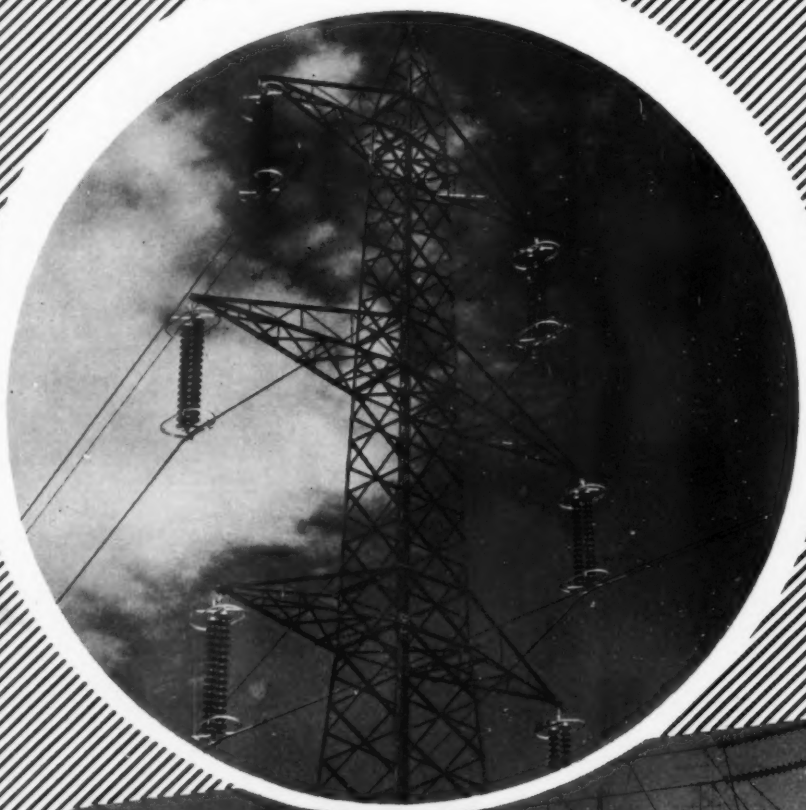

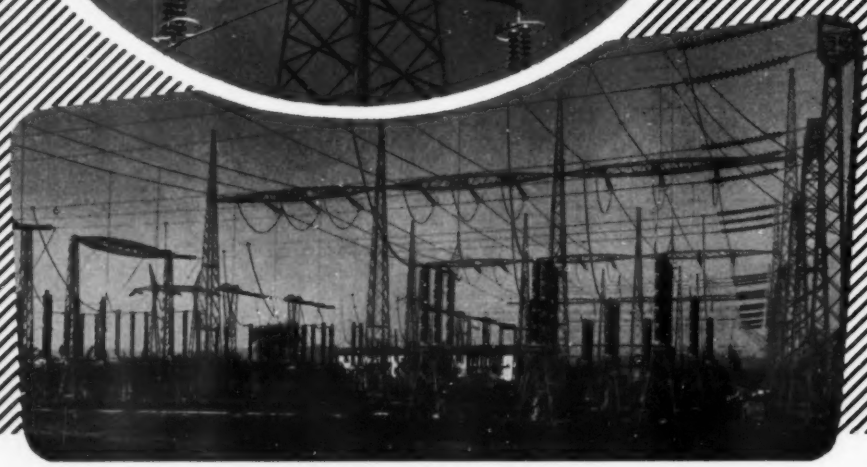

For 30 years Messrs. A. Salvi and Company, Milano, Italy, have specialized in the design and manufacture of complete equipment for Overhead Transmission Lines, including Compression Dead End Assemblies and Joints. The Works of the Salvi Company are engaged exclusively in the production of high grade fittings for High Voltage Transmission Systems, up to and including voltages of 220/380 KV and for all sizes of Copper, A.C.S.R. and Aluminium Alloy Conductors.

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ESCHER WYSS
turbines near the Arctic Circle

The 83,400 HP Kaplan turbines for Pirttikoski Power Station in Finland represent another example of our activities as suppliers of Hydraulic Installations throughout the world. These units are designed to operate at 115.4 rpm under 29 metres head with 232 cub. m/sec. developing unit outputs of 83,400 HP.

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GLENFIELD VALVES
for Free Discharge

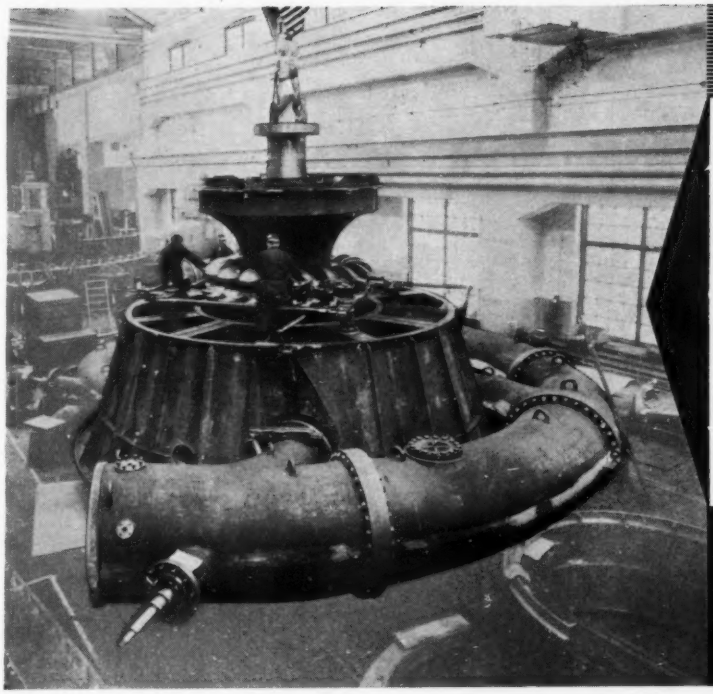
Glenfield Valves for regulating the flow and dissipating the energy of water released from dams for compensation or scour purposes under free discharge conditions are widely applied, and include Hollow Jet, Needle and Sleeve types; the needle style incorporated Glenfield Jet Dispersers.

Illustrated is a 60 in. dia. Needle Valve with Jet Disperser in operation, and a general view of a 72 in. dia. Sleeve Valve.

Glenfield

GLENFIELD & KENNEDY, LIMITED, KILMARNOCK

Head Office and Works: KILMARNOCK, SCOTLAND

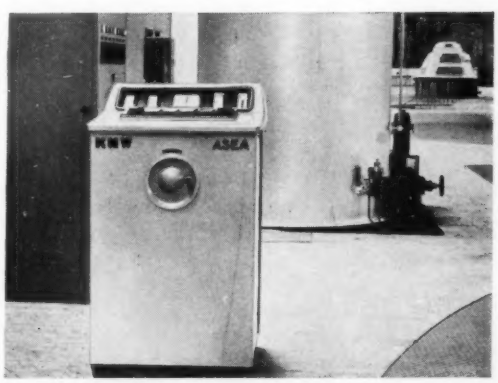


The Largest Vertical

PELTON Turbines

in Norway are KMW Turbines

In the last half of 1958 the first of the two Pelton Turbines ordered from KMW by the Hjartdöla Power Station in Norway was put into operation; the second unit was put into service in May, 1959. Each turbine has a nominal output of 71,000 H.P. at 555 m (1,820 ft.) net head and 428 r.p.m.



Both the turbines are equipped with the ASEA-KMW system of electro-hydraulic governing. Impulses from the electronic regulator are converted into mechanical motion in the electro-hydraulic actuator. This motion is transmitted via a separate servomotor to the deflectors and the control valves of the needle servomotors, which are linked by a conventional system of cams to provide the correct combination of controls.

This is the first time that ASEA-KMW electro-hydraulic actuators have been used for Pelton turbines, and this regulating system has proved to operate perfectly. Alterations in speed when throwing-off load are very small and the return to normal revolutions is remarkably quick.

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Karlstad - Sweden

Representatives in Canada: A. Johnson & Co. (Canada) Ltd.
607 Shell Tower Building, Montreal 2.

KMW

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Henderson again leads the field in Derrick Crane Design

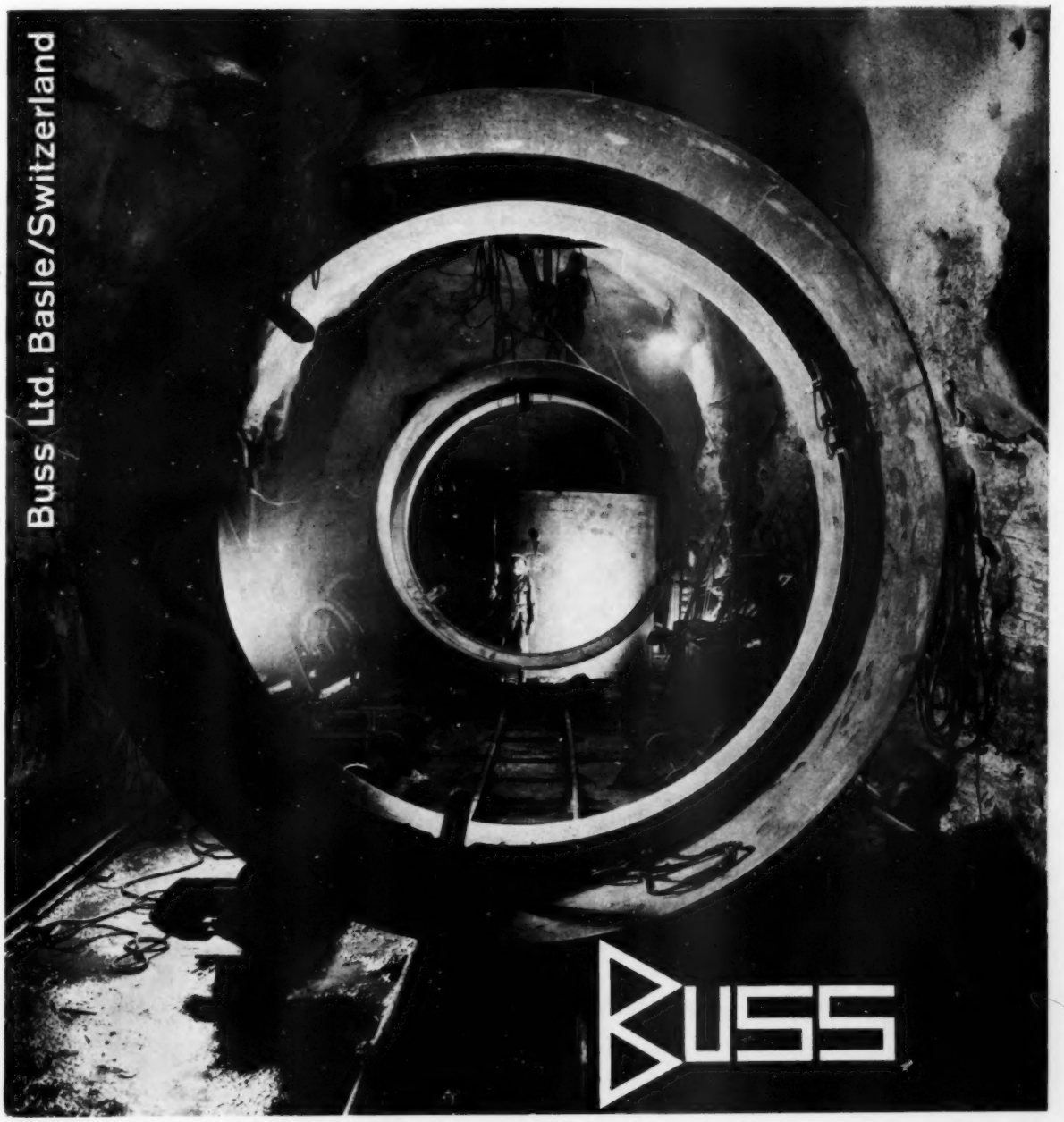
Gruidae Hendersoniis (HENDERSON'S CRANE)

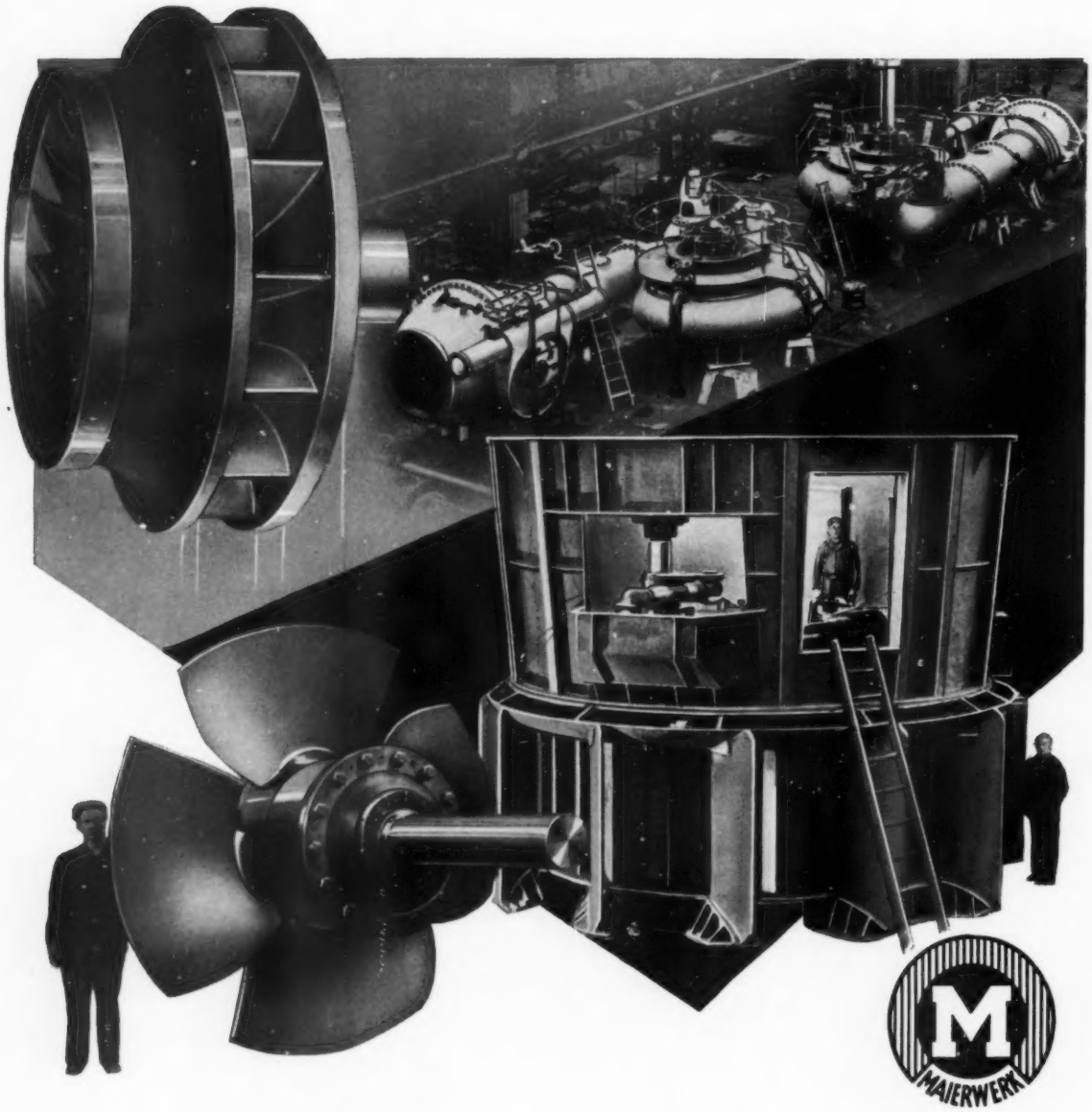
Discovered by John M. Henderson in Aberdeen, HENDERSON'S CRANES are native to Scotland but are found in great numbers in all parts of the world. Easily the finest specimens of a numerous species, their vigorous characteristics are unimpaired by climatic variations. Rising to great heights, they perform prodigies of strength and are noted for their stamina and longevity. Friends to man, they roost wherever he is breaking new ground and render great service by eradicating the common handling bug (*chaos extremens vulgaris*), frequent cause of industrial paralysis.

JOHN M. HENDERSON & CO. LTD · KING'S WORKS · ABERDEEN · SCOTLAND

specialized

in penstocks and pressure shaft linings as well as in other equipment for hydro-electric power plants





The above photos represent **High-pressure Spiral-Turbines** in our workshops with mounted **spherical valve** as well as an appertaining runner of stainless cast steel, cast in one piece.

One **Kaplan-Turbine** in our erection workshops with appertaining **Kaplan-runner** also of stainless steel.

Every one of our runners is carefully tested in our laboratories as well from the hydraulic point of view as with regard to the security against cavitation.

MASCHINENFABRIK B. MAIER

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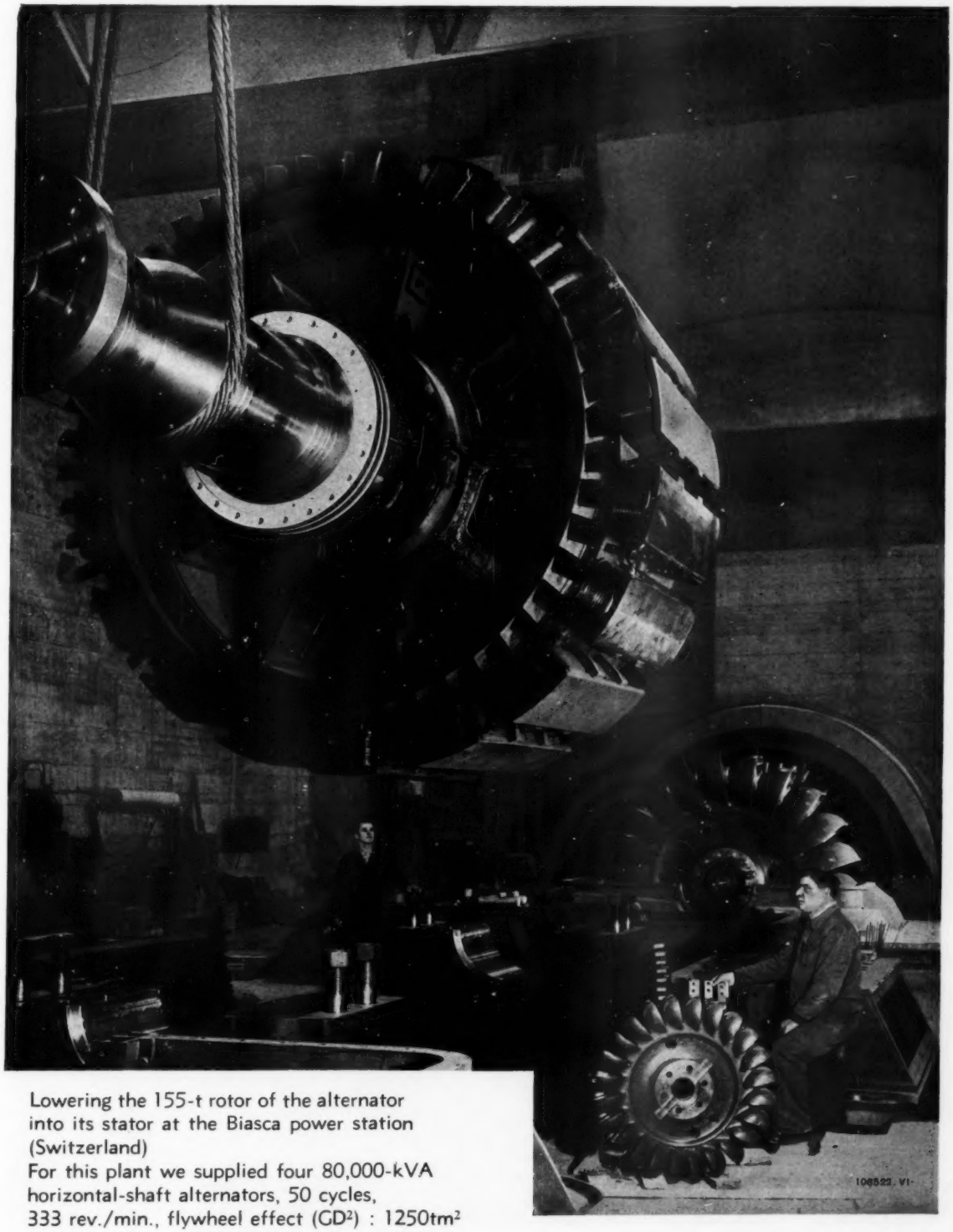
BROWN BOVERI WATERWHEEL GENERATORS



Lowering the 155-t rotor of the alternator into its stator at the Biasca power station (Switzerland)
For this plant we supplied four 80,000-kVA horizontal-shaft alternators, 50 cycles, 333 rev./min., flywheel effect (GD^2) : 1250tm^2 each coupled to a 100000 h.p. Pelton turbine

BROWN, BOVERI & CO., LTD., BADEN
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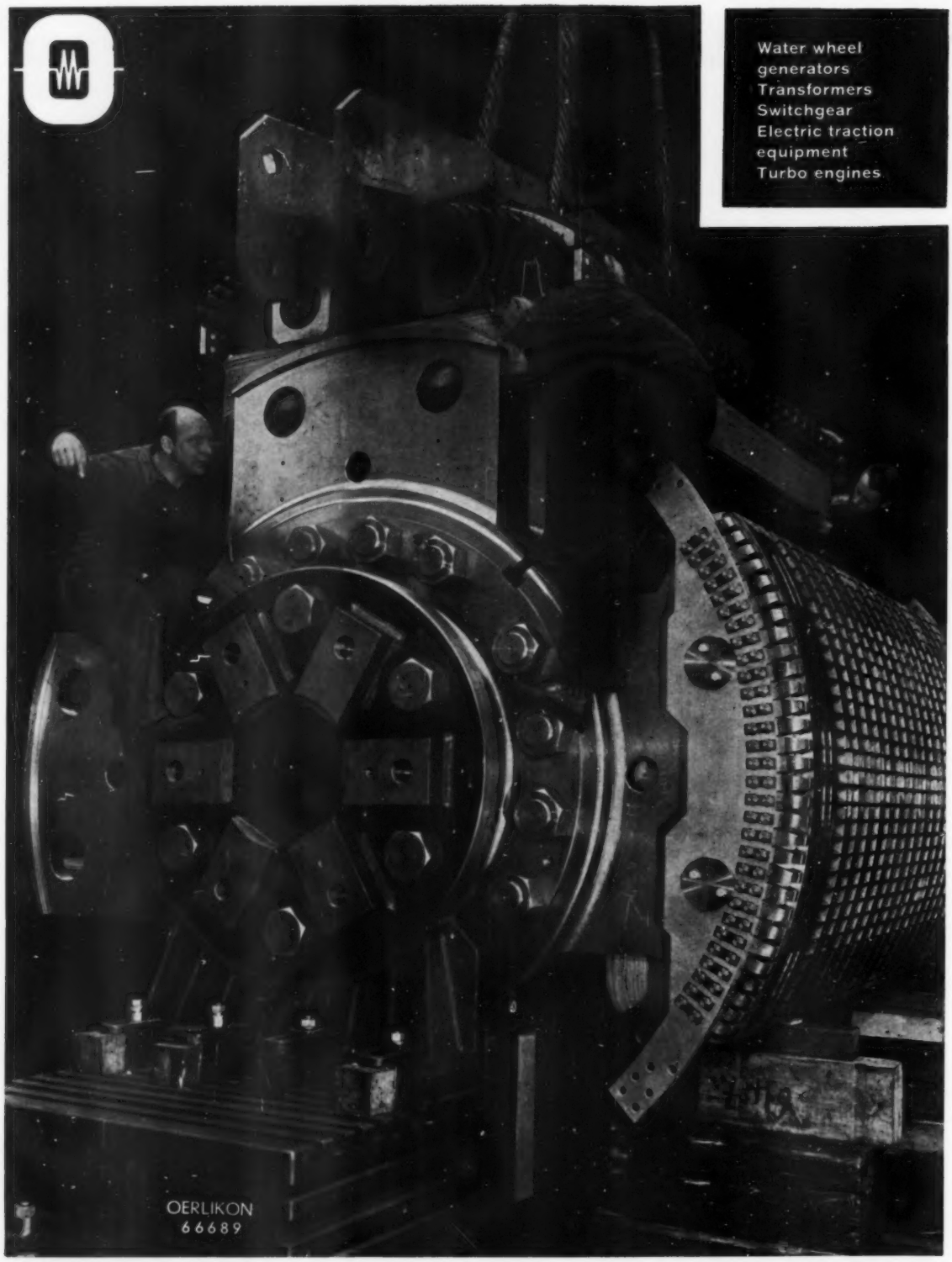
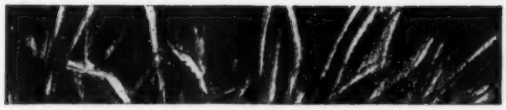
BROWN BOVERI



Oerlikon Engineering Company • Zurich 50 (Switzerland)

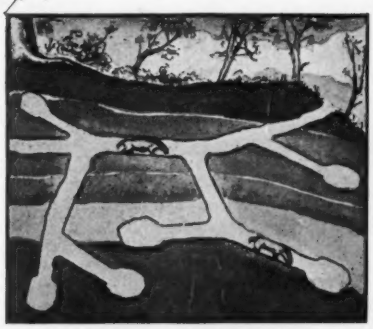


Underground movement

A long tunneller and a strong tunneller, the badger builds himself an intricate web of passages and dens in which to evade pursuit or retire from the noisy world outside.

It's a paradox of progress that man too—in getting even further away from nature—is going more and more underground. Tunnels for hydro-electric schemes, underground power houses—these and many other engineering feats are the work of man the tunneller—a skill which we have developed into a fine art. * *

* * In driving 40 miles of tunnels for the North of Scotland Hydro-Electric Board, Mitchell Construction captured and hold the World high speed rock-tunnelling record and constructed the first major underground power station in Britain.



Many of these badger 'sets' have been enlarged and improved through successive generations and may extend for hundreds of feet into a hillside.

MITCHELL CONSTRUCTION

Building and Civil Engineering Contractors

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PENSTOCKS, PRESSURE SHAFT LININGS FOR ALL WORKING PRESSURES

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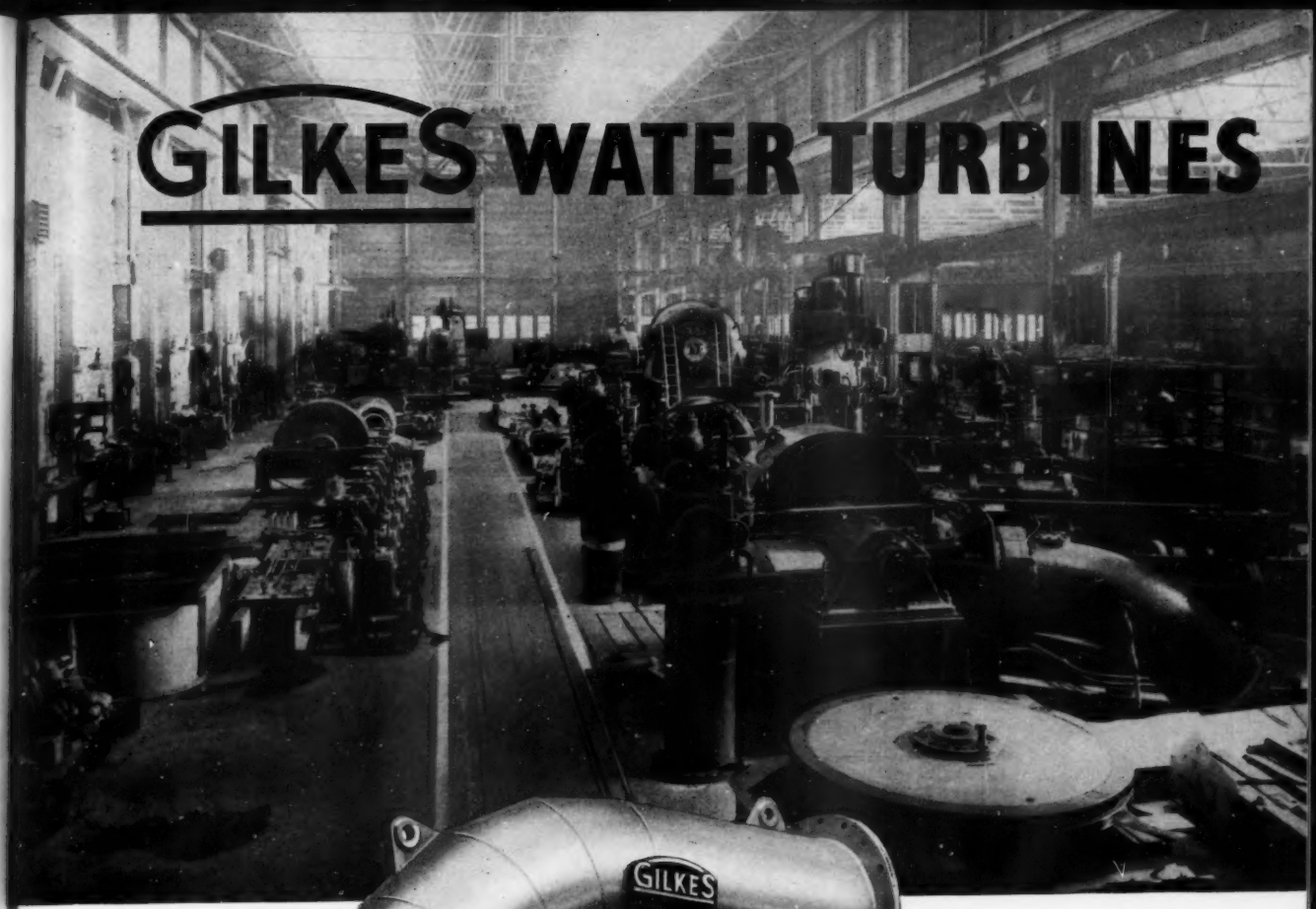
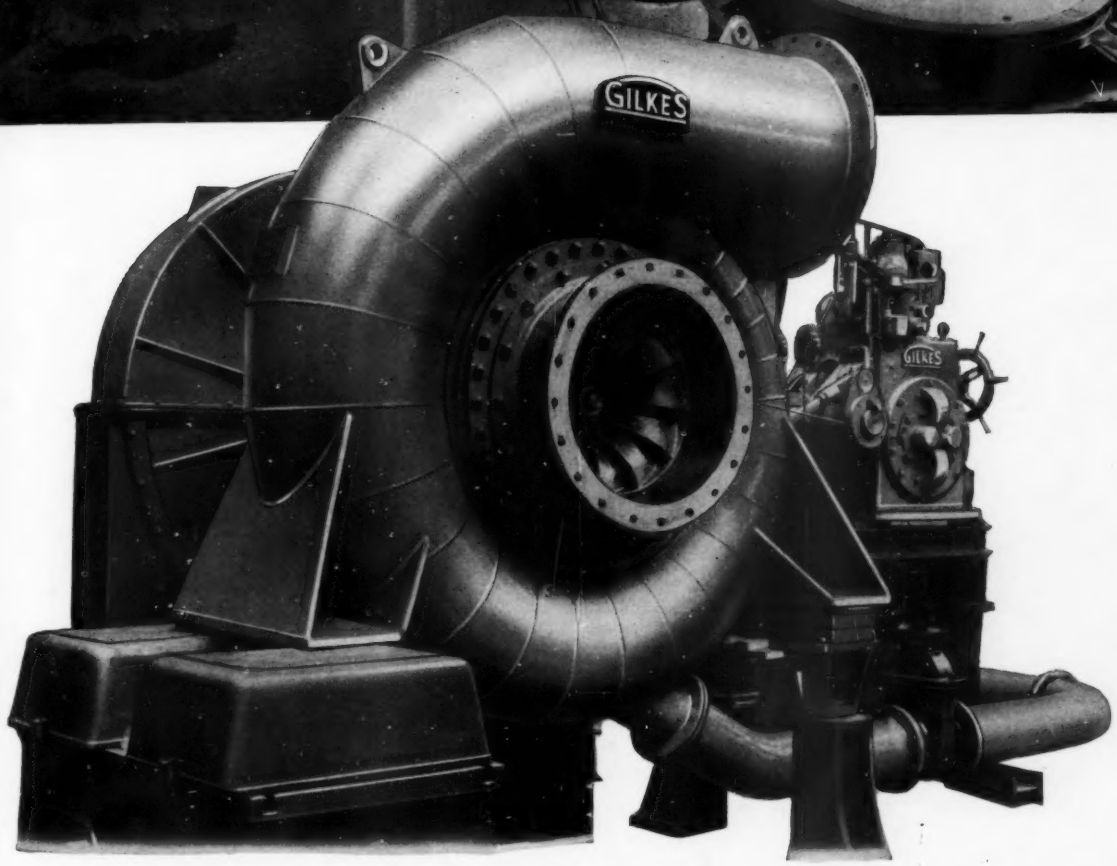
GILKES WATER TURBINES





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Pre-stressed reinforced concrete pipe, diameter 3.30m. pressure 9 atm. Brunico hydro-electric power station, Italy. Soc. Montecatini

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VENICE (ITALY) - Accademia 979/A - Telephone 85.060

Type CD, outdoor, de-ion grids,
oil circuit breaker from 60
to 160 kV - 600 A.

MAGRINI'S TRADE-MARK AND SWITCHGEAR WIN WORLD-WIDE RECOGNITION

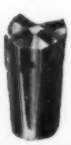
MAGRINI S.P.A. - VIA L. MAGRINI 7 - BERGAMO - ITALY

Victor

A name to remember in percussive drilling!

Victor Percussive Bits

Victor percussive bits bring NEW economy to drilling jobs where solid tipped steels are unsuitable. Available in chisel or cross types, Victor tungsten carbide tipped percussive bits are manufactured in a complete range of sizes for ex-stock delivery. If you are interested in minimising drilling costs please write for full information.



Victor Drill Steels

With the advantages of "High Temperature" brazing technique for tip-fixing and controlled manufacture, Victor now offer the ultimate in drill steels — steels which give the operator greater footage and faster drilling.

Victor experience in drilling techniques now makes available a range of drill steels designed for top performance in the toughest conditions.

Victor Products (Wallsend) Limited

Wallsend-on-Tyne, England **Telephone: Wallsend 68331 (6 lines)** **Cables: 'Victor' Wallsend, England**

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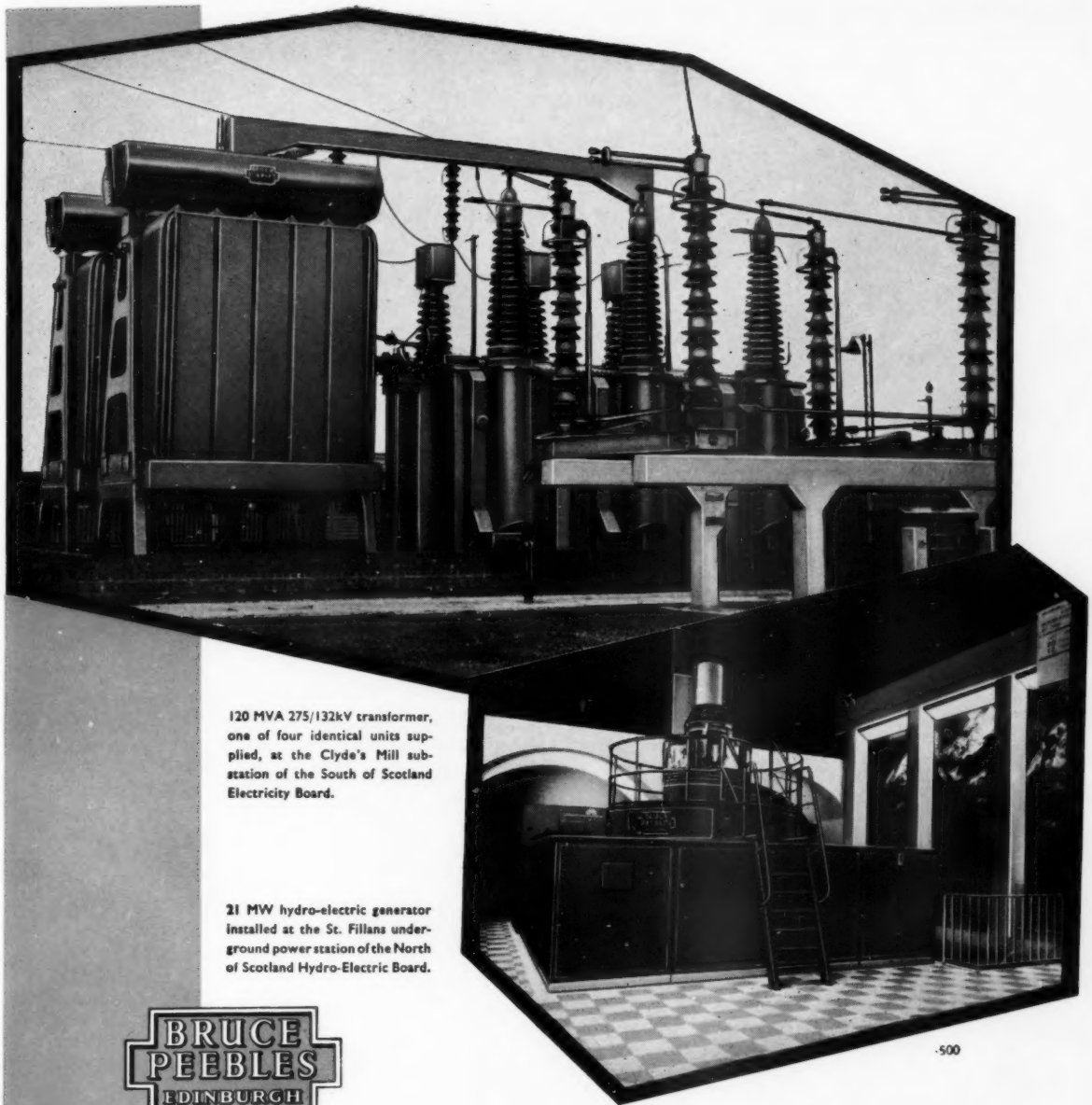


120 MVA 275/132kV transformer, one of four identical units supplied, at the Clyde's Mill substation of the South of Scotland Electricity Board.

21 MW hydro-electric generator installed at the St. Fillans underground power station of the North of Scotland Hydro-Electric Board.

BRUCE PEEBLES EDINBURGH

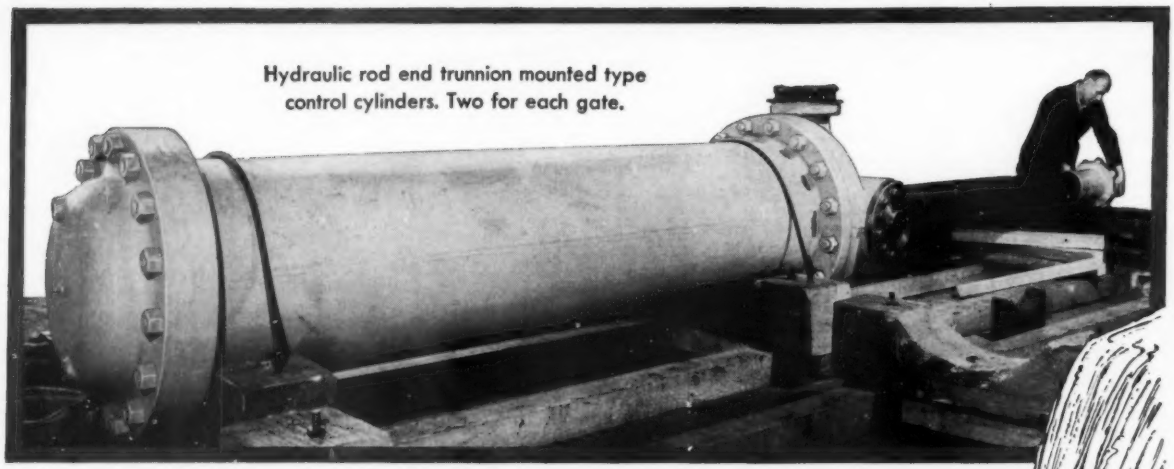
HEAVY ELECTRICAL ENGINEERING

Bruce Peebles & Co. Limited, are playing a leading role in the manufacture and supply of large hydro-electric generators and transformers up to the largest sizes and highest voltages, for important power development schemes at home and abroad.

Long years of experience have resulted in the modern methods employed in manufacture and in the efficient works equipment necessary to meet the high standards maintained by the Company.

Ample resources for manufacture and testing enable the largest contracts to be undertaken.

BRUCE PEEBLES & CO LIMITED · EDINBURGH · SCOTLAND



Hydraulic rod end trunnion mounted type control cylinders. Two for each gate.

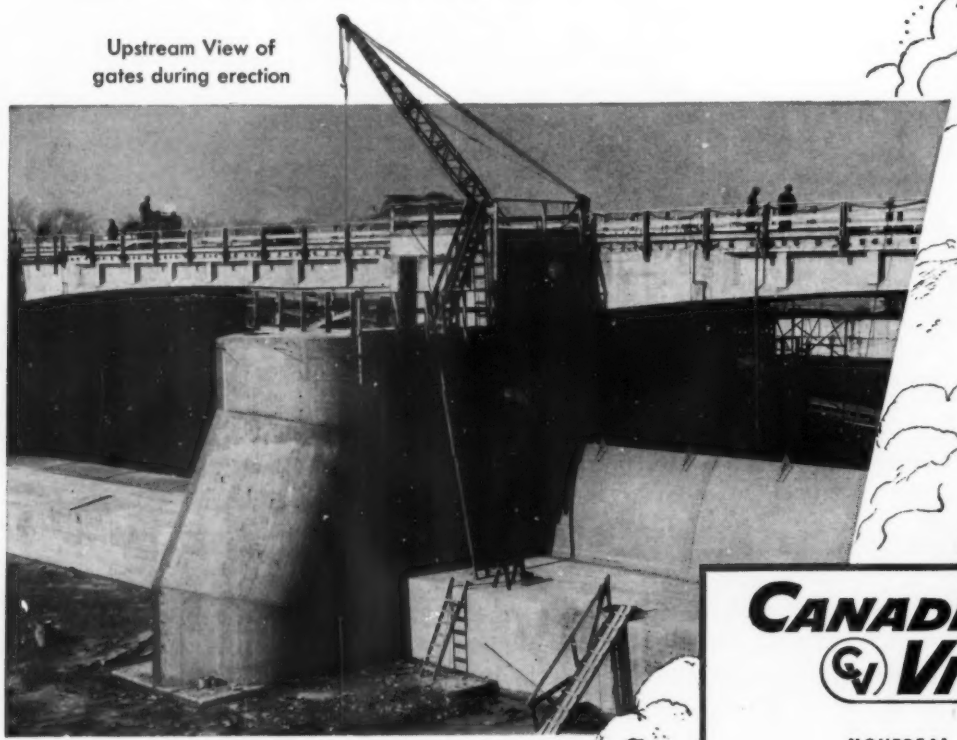
CONTROLLING THE FLOW OF NIAGARA

The flow of Niagara, one of Canada's greatest sources of electric power, is controlled by Vickers-built submersible gates of the "fishbelly" type.

Working with the M.A.N. Company, a Canadian Vickers associate, who designed the 100 ft. wide section welded gates, thirteen gates were supplied along with twenty-six servomotors and thirteen pumping sets which were entirely engineered by Canadian Vickers.

These gates are another example of the precise engineering that goes into all Vickers-built water control equipment.

Upstream View of gates during erection



CANADIAN VICKERS LIMITED

MONTREAL • TORONTO

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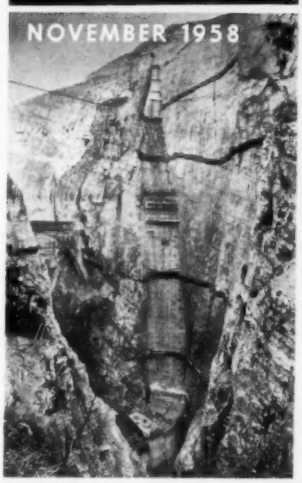

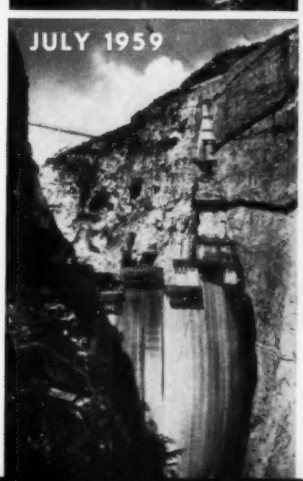

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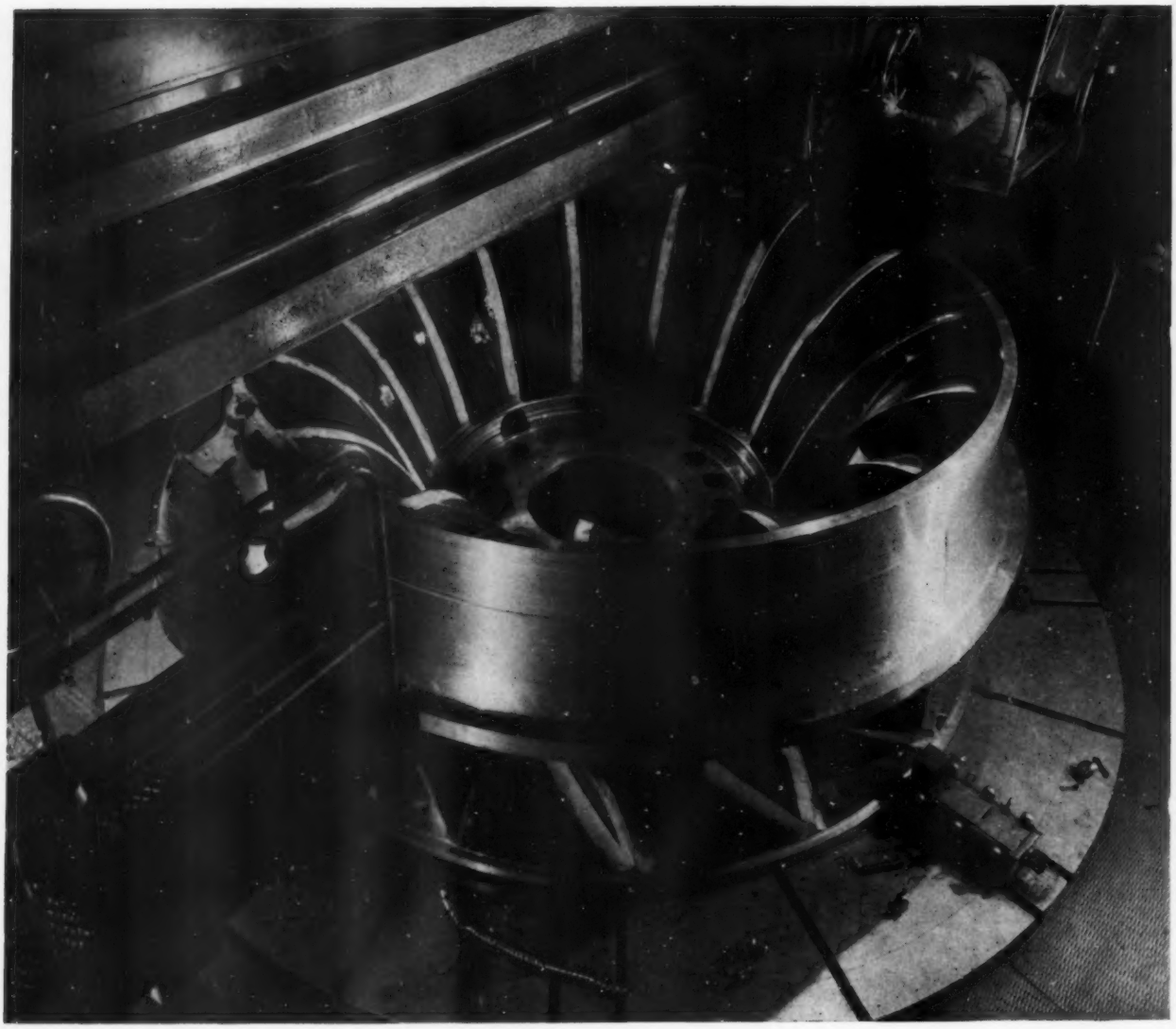

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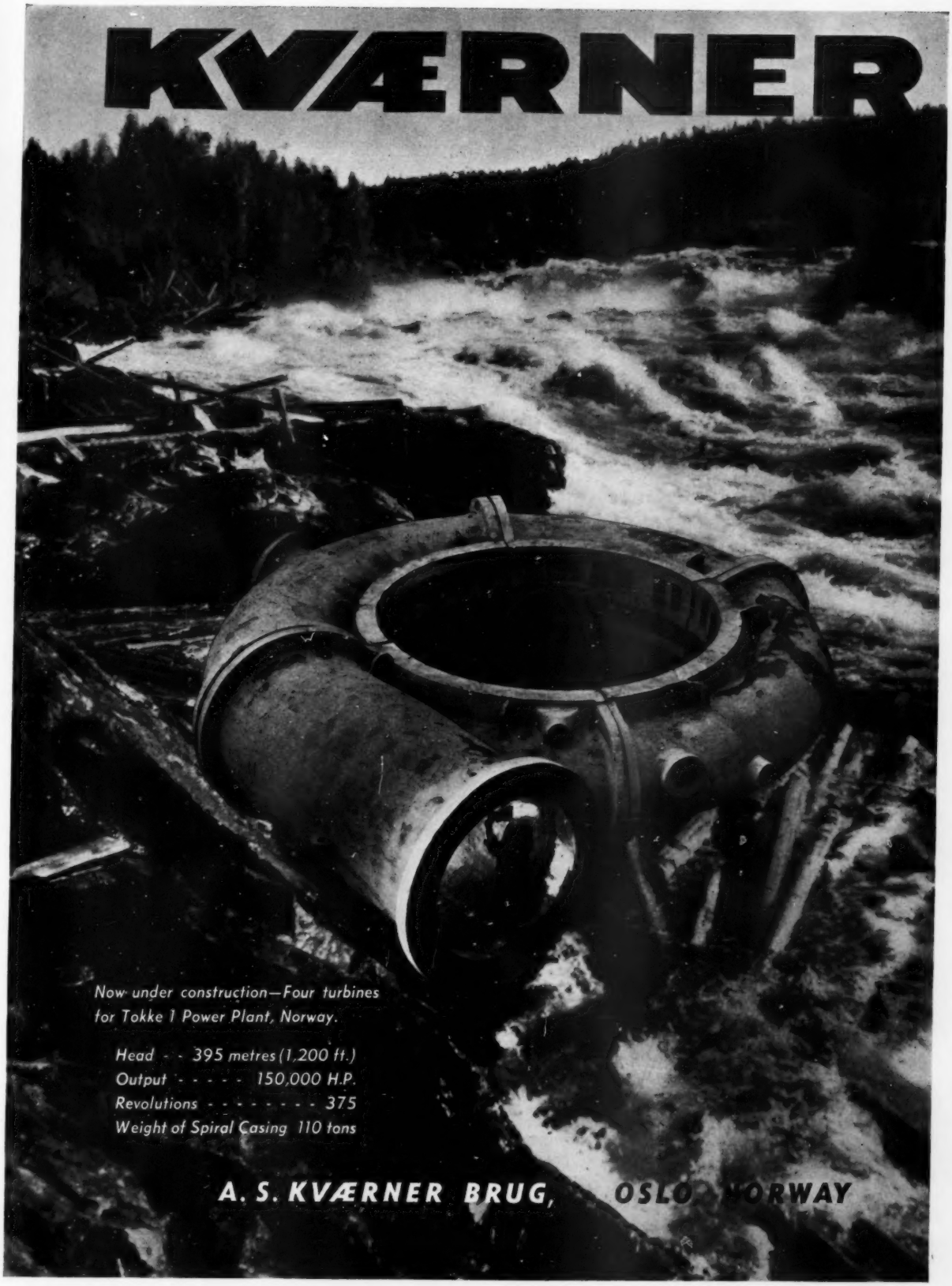
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Volume 12 Number 1

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Editor : H. STOREY, M.C., B.Sc., M.I.M.E.

PUBLISHED BY TOTHILL PRESS LIMITED
33 Tothill Street, Westminster, London, S.W.1
Telegrams: Trazette, Parl, London. Telephone: Whitehall 9233 (20 lines)

MANCHESTER: Century Insurance Building, St. Peter's Square. Telephone: Central 7667/8/9
BIRMINGHAM: 90 Hagley Road, Edgbaston. Telephone: Edgbaston 2466
NEWCASTLE-ON-TYNE: 21 Mosley Street. Telephone: 22239
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WATER POWER

A technical journal devoted to the study of all aspects of hydro-electric development

The Tragedy at Malpasset

ON December 2, 1959, over three hundred people were killed and vast damage was caused to property in the vicinity of the Malpasset dam on the river Reyran in southern France, near the French Rivièra. The dam was built to ensure the supply of drinking water and irrigation water for that region of the Department of Var lying between the Alpes-Maritimes on the east and St. Tropez on the west.

Studies were commenced in 1945 by the Chief Engineer of the Rural Services Department, and the Malpasset site was chosen in order to accumulate the waters of the Reyran, the Biançon and Siagnole. Studies extending over five years were undertaken, and the regime of the river Reyran, which is torrential in nature, was assessed. The greatest flood recorded in summer was 120 cu. m. per sec. for five hours. The river is dry, on the average, for two months in each year. The volume of water capable of being stored, in a year of average rainfall, would be about 22,750,000 cu. m.

It was decided that as the basin at the site of the dam at Malpasset was made of a synclinal carboniferous zone, enclosed by the metamorphic horizons of the base Massif of the Esterel, a thin arch dam, of what was stated at the time to be an economical design, would provide a perfectly sound and watertight structure. The consulting engineers, Coyne and Bellier, were called in to assist with the planning of the project. The thin-arch dam, of semi-circular form, is built at a site where the profile along the valley takes the form of a trapezium. The dam rested on a rocky peak on the right bank and on the left bank on an abutment protected by a wing wall. It rose 60 m. above the bed of the river. The maximum thickness at the base was 6·91 m. and the thickness at the crest was no greater than 1·5 m. The upstream radius at the crest was 105 m. A spillway had allowed for the evacuation of 180 cu. m. per sec. at the highest water level. The drainage arrangement for the dam consisted of a steel conduit, 1·5 m. in diameter, passing radially through the foot of the dam.

Building work commenced on April 1, 1952, and the granular composition of the concrete is perhaps of special interest. It was as follows:

mm.		kg. per cu. m.
0– 4	seaside sand	185
0– 4	crushed materials	185
4– 10		202
10– 25		243
25– 65		498
65–125		684
Cement		300
Water		175
		2,472

(Average cement-to-water ratio 1·76)

The enquiry into the failure of the dam may well result in considerable attention being paid to the method of construction, since photographs of the burst indicate that the concrete has broken away in steps, which may well coincide with the joins created during construction. The arch was constructed in 17 independent sections with an average length of 13·5 m., these sections being separated by contraction joints. The sections were poured in lifts of 1·50 m. The concreting of adjacent sections was spaced out by about three lifts.

The whole project required the placing of about 48,000 cu. m. of concrete and the works were carried out by the Entreprises Léon Ballot and Gianotti Frères. The dam at Malpasset, is typical in some ways of modern French thought on thin-arch structures. It appears to typify the design adopted in many brilliantly conceived hydro-electric projects throughout France and French territories overseas. It cannot be thought that the tragedy at Malpasset casts doubts, by inference, on other generally similar thin-arch dams in France and elsewhere. Many of these have been in service for a considerable period without the slightest sign of a fault of any kind. The cause of the disaster at Malpasset must remain for the official enquiry to determine; but it is at least possible that

1959 INDEX

An index to WATER POWER for 1959 has been prepared and can be obtained free of charge on application to the publishers.

constructional rather than design defects may perhaps be blamed for the collapsing of this great structure, or that the disaster may have been due to a failure of the foundation rock.

The sympathy of all our readers will of course be abundantly directed towards the victims who lost their lives and others who lost their homes and relatives in this dreadful occurrence; but hydro-electric engineers everywhere will have great sympathy, as well, for the designers and constructors who had, only a few weeks before, participated in an official inauguration ceremony. Anyone engaged in fighting against nature must appreciate the daring that lies behind any and every design. With the French genius for civil engineering and, in particular, for the development of dams of all kinds, it could never be said that there was any lack of skill in the conception of this project. It is to be hoped that the lessons learned during the enquiry will be made freely available to civil engineers in all parts of the world.

It is especially important that the earliest possible steps should be taken to elucidate the reason for the Malpasset failure, since there have been two other incidents in the last twelve months, which may tend to undermine public confidence in the skill of civil engineers. The Rivadelago dam at Vega De Tara, in Spain, gave way in January, 1959, and there was a considerable loss of life. The hoist chamber of the Bhakra dam, in India, gave way in August, and great damage to costly machinery, as well as a delay in the execution of this important project, was the result.

The lessons learned from these three failures will doubtless do much to assist civil engineers to guard against similar disasters in the future.

Dokan Dam

AT an exceptionally well-attended meeting of the Institution of Civil Engineers last November, two papers were presented on the recently completed Dokan dam on the Lesser Zab in Iraq. The first paper, on the dam itself, was presented by G. M. Binnie, J. G. Campbell, R. H. Edgington, C. A. Fogden and N. H. Gimson, whereas in the list of authors for the second paper, on the flood-disposal works and the grouted cut-off curtain, R. H. Edgington and C. A. Fogden were replaced by P. F. F. Lancaster-Jones and C. A. Gillott.

Dokan dam—which has been constructed primarily for irrigation but has provision for a 200 MW power station—has many points of interest. It is a pioneer design in that it is the only dam in the world to have been calculated by relaxation methods. This was carried out by a team at Imperial College, London, under Prof. A. J. S. Pippard, and was the subject of an earlier paper read before the Institution (see WATER POWER, March 1956, p. 83). Owing to the wide temperature variations experienced at the site, the concrete was cooled, both by cooled mixing water and by embedded cooling coils, and an exacting cooling schedule was enforced. The bellmouth spillway, 40·26 m. in diameter, is believed to be the largest in the world, and the geology of the site necessitated the formation of a grout curtain about 1 km. long on each side of of the dam as well as extensive foundation grouting.

The papers were practical in the best sense, and gave many details of the design, the construction methods, and the difficulties encountered and overcome. An excellent colour film of the construction was shown during the evening.

The consulting engineers for the scheme were Messrs. Binnie, Deacon & Gourley.

Hungarian Power Stations for Ghana?

DISCUSSIONS are going on between Hungary and Ghana about the possibility of building two hydro-electric power stations on the rivers Pra and Densu. These talks are the outcome of a visit to Ghana by two officials of the Budapest Ganz-Mávag Electrical Works, at the invitation of a leading official of the Electrification Board of Ghana.

Hungary is already supplying hydro-electric plant to Turkey, India, Bulgaria, the Soviet Union, Poland, Albania and China.

Boving Australasian and Scottish Contracts

CONTRACTS have recently been awarded to Boving & Co. Ltd. for turbines and valves for four power stations in Australia, New Zealand and Scotland.

The largest of the four is for the underground Poatina power station of the Hydro-Electric Commission of Tasmania, where eventually six 82,500 h.p. 600 r.p.m. vertical four-jet impulse turbines will be installed. The present order covers four turbines with six 36 in. diameter pipeline isolating valves as well as four turbine inlet valves, all of the Boving rotary type. The maximum operating head will be 2,720 ft., the highest for any hydro-electric installation in Australia. The turbines will draw water from the Great Lake in the centre of Tasmania. Incidentally, in 1916, Boving supplied seven 8,000 h.p. 1,000 ft. head turbines which are still operating, for the first power station to use the waters of the Great Lake.

The second contract is for two 47,000 h.p. 600 r.p.m. 939 ft. head Francis turbines, with pressure relief valves and 48 in. diameter Boving rotary valves, for the Barron Gorge power station, also underground, of the State Electricity Commission of Queensland.

The other orders comprise one 40,500 h.p. 167 r.p.m. 107·5 ft. head Kaplan turbine for the Inverawe power station of The North of Scotland Hydro-Electric Board, and one 4,000 h.p. 600 r.p.m. 210 ft. head Francis turbine with inlet valve and two automatic self-closing butterfly valves for protection of the pipelines for the Kuratau power station of the King Country Electric Power Board, New Zealand.

Northern Canada Power Commission Annual Report

THE annual report of the Northern Canada Power Commission for the year ending March 31, 1959, has recently been published.

Of interest to the water-power engineer, it was noted that the Snare River hydro power plant operated at full capacity, except for the summer months, generating 46,369,000 kWh, a slight improvement on the previous year. The Commission is now proceeding with the development of the Snare Falls for a second hydro power station, some 10 miles downstream of

the existing plant. The Mayo River hydro-electric plant increased its output by 79% to 34,076,000 kWh due to the addition of No. 2 generating unit which encountered no difficulties.

Construction on the Whitehorse Rapids power development was continued whereby the first generating unit was put in operation in November 1958 and which had generated 7,153,500 kWh by the end of that year. This plant consists mainly of an earthfill dam across the Yukon River with a concrete spillway structure embodying two large sluice gates. No fishway facilities had been incorporated and the Federal Government decided that such facilities should be provided at an estimated cost of $1 million. An agreement has also been reached regarding the construction of transmission lines with associated terminal station with the New Brunswick Electric Power Commission. The total amount of the contract is just over $1 million.

Transmission Link in Ceylon

THE main work on the 66 kW transmission line linking the Inginiyagala hydro-electric power station in Gal Oya in south Ceylon with Badulla in the middle of the island, thus connecting the main island grid, will begin in early 1960. This is the assurance given by Mr. Shelton Ross, representative of the Canadian Government, who was here to investigate the transmission link-up. Mr. Ross said that they had examined the Inginiyagala power plant with a view to expanding the capacity of the plant with two additional generating units. The preliminary survey for the implementation of the proposed interconnecting transmission line to the main island grid at Badulla has already begun.

The project is expected to cost about Rs. 8,000,000. The engineering services, design, supervision of construction and the necessary equipment would be made available by the Canadian Government under the Colombo Plan. Meanwhile, the rural electrification scheme of the Ceylon Government is to be extended to Pamunugama as a first step towards providing electricity to the villages. The power will be obtained from the hydro-electric scheme at Laxapana in central Ceylon.

Exploitation of Water Sources in Madras

MADRAS is the only State in India which has exploited all utilisable water resources in the area. This was stated by Mr. J. Hathi, Deputy Minister for Irrigation, Government of India, at a conference held at Periyar. The conference was held to review the progress of irrigation and power projects in the region. Mr. Hathi said that out of the 1,600,000 acres of land, 1,300,000 had benefited from various irrigation projects, while the power generation had more than doubled to 370,000 kW during the past five years and would increase to 570,000 kW with the completion of the Neiveli and Pambayar projects. Already, 8,000 villages in Madras State are enjoying hydro-power.

Regarding the harnessing of the river Godavari in Andhra State, Mr. Hathi said that this and other schemes for tapping rivers from the Western Ghats were already being considered. Several members of Parliament who were present at the conference said that an atomic power station should now be started in Madras State as available sources of water power had already been tapped, and the State's power needs were growing. Schemes for utilisation of the Godavari river water will be considered during the third Five-Year Plan. Andhra Government is now preparing these schemes.

In Madras State out of 16,000,000 acre-ft. of water, 13,000,000 have been utilised and a further acreage of 1,500,000 is being utilised in the second Five-Year Plan period, leaving almost nothing for further use.

Indo-Bhutan Agreement

AN agreement has been concluded between India and Bhutan on the Jaldhaka hydro-electric project to be undertaken by the Government of West Bengal. Under the agreement, Bhutan will receive 250 kW of power free of cost. The West Bengal Government will also pay an annual royalty of Rs. 8 per kW to the Bhutan Government for the rest of the power generated from the first stage of the project. Jaldhaka is a small river rising from the Himalayas. Draining a catchment of about 172 sq. miles, the river constitutes the boundary between West Bengal and Bhutan for about 12 miles. The firm power potential of the first stage of the project has been estimated at 18,000 kW at 50 per cent. load power. The initial installation will comprise two generating units, 9,000 kW each. Provision will be made for further addition of two more units of 9,000 kW for generation of seasonal power.

The first stage works costing Rs. 29,000,000 on power generation and Rs. 14,600,000 on transmission equipment, are expected to be completed in about three years.

Benmore to be 540 MW in Capacity

THE New Zealand Government has decided to increase the rating of the six generators to be installed at Benmore from 80 to 90 MW, so that the aggregate capacity of the station will be raised from 480 to 540 MW. At this capacity, it is claimed, Benmore will be the largest hydro-electric station in the Southern Hemisphere.

Economic Commission for Europe Visits Scotland

TWENTY-ONE members of a working party of the Economic Commission for Europe who are studying rural electrification in Britain visited Oban, Argyll, towards the end of last year. They were led by Professor N. Sansanov, Director of Technical Sciences for Bielorussia.

The delegates—electrical, agricultural and economic experts from 14 countries—were welcomed by Mr. J. C. N. Baillie, chief commercial engineer of the North of Scotland Hydro-Electric Board, who told them the Board was now supplying 26,000 farms and crofts with electricity. Mr. Baillie intimated that the extension of supplies in rural areas had already cost nearly £30 million and would continue as fast as the finances of the Board would allow.

Professor Sansanov, speaking for the delegation through an interpreter, said the task given to them

included an investigation of problems arising from electro-mechanisation in agricultural areas. From these investigations they would produce reports which would be circulated to various countries not only in Europe but in the Far East and Asia. In this way, he added, we hope to contribute to rural electrification in all countries. He expressed his interest in seeing how electricity was helping the Scottish farmer to increase his production and develop his undertaking and considered that the standard of the installations in Scotland, although small, were equal in efficiency to any that the Commission had seen. The working party has already visited the Soviet Union, Austria and Italy.

Irrigation and Power in Rajasthan

THE Government of Rajasthan, India, will shortly undertake a survey of the irrigation and power potential of the State. Under a scheme, which is being taken up by the State Government, each river basin will be dealt with separately and the possibilities of constructing minor irrigation works will be surveyed. Before this is done, the catchments and the location of all existing works will be clearly shown in the plan of the basins to ensure that time and energy are not wasted on schemes which would interfere with the supply to the present works.

As the number of small catchments in the State is small, they will be taken up one by one and each will be completed before passing on to the next one. In practice, all schemes costing Rs. 5,000 will be considered.

Power in Perak

IN the year ending July 31, 1959, The Perak River Hydro Electric Co. Ltd., Malaya, report that the production of energy was adversely affected by the reduced quota for tin exports. Some 85% of the company's production of power is consumed by the tin companies and a reduction of 30% in the production of tin naturally affected the power situation. Furthermore, the flow of the Chenderoh river was the lowest for some 30 years and this has caused more current to be produced by the electricity company's thermal plant. Normally, under reasonable conditions of flow, the Chenderoh stations produce 190 million kWh, but in the year under review only 142 million kWh were produced, about 18% less. The higher rate of tin production suggests better prospects for the future.

Harnessing the Gandak

COMPLETE accord has been reached over the execution of the Gandak project which will irrigate about 4,000,000 acres of land in Nepal, Bihar and Uttar Pradesh and also supply power. The project envisages the construction of a barrage across the Gandak river on the Indo-Nepal border, the laying of a cable system on either side of the river and the construction of a water power station in Nepal territory.

The accord comes after three years of negotiations on the project between India and Nepal. Under the terms of agreement, India will construct a power house in Nepal territory with a capacity to generate 10,000 kW of power which is to be given to Nepal free of cost. The Nepalese people will get electricity from this power house at production cost. India will also have to finance the construction of village channels in Nepal having a discharge of five to 20 cusecs. This will provide irrigation in Nepal to an additional 20,000 acres of agricultural land.

The cost of the project is Rs. 520,000,000. Bihar and Uttar Pradesh will share the cost of the project in proportion to the benefits derived by them. The entire project is expected to be completed in six to seven years.

Power Potential of Ganga Basin

ON the basis of a survey conducted by the Central Water and Power Commission of India, the power potential of the Ganga river basin has been estimated to be as high as 13,000 MW. The Ganga basin in India is one of the six regions which are being surveyed by the Commission to prepare a complete and accurate picture of the country's hydro-electric resources.

Of the six regions, five have now been surveyed and the only area which remains to be studied is part of the Indus basin. The survey of power potential in this region will, however, await settlement of the Indo-Pakistan canal water dispute.

There are over 50 different sites on the Ganga and its numerous tributaries which offer scope for power generation, varying from 10 MW to 1,600 MW. The power potential of the basin is thus much larger than that of the rivers in South India which were similarly surveyed some time ago. On the Ganga, a natural dam site exists at Kotibhel, 36 miles upstream of Hardwar, with scope to generate nearly 600 MW of firm power, and a little distance downstream there is a further site where nearly 400 MW can be developed.

Australian Ideas May Help Burma's Power Development

TWO engineers from the Electricity Supply Board of Burma are studying the power distribution methods of the State Electricity Commission of Victoria, Australia. They consider that Victorian ideas may be useful to Burma in the country's plan to build a uniform electricity supply network to which all power stations will be linked.

The engineers are U Kyaw Nyein and U Kyaw Nyunt. U Kyaw Nyein will spend a year in Australia studying the design of power distribution systems and U Kyaw Nyunt will be in Australia for two years studying the construction and maintenance of these transmission lines and substations.

Kaplan Turbines for Swedish Power Plant

THE Swedish State Power Board have ordered two KMW turbines of Kaplan type for their new Laxede power plant on the Lule river, situated about 95 km. (59 miles) north-west of the city of Luleå in Northern Sweden. Each turbine is for an output of 89,000 h.p. at 25·4 m. (83 ft.) head and a speed of 107 revs. per min. In principle, the design will be the same as for the two turbines for the Swedish power plant Järkvissle. The delivery to Laxede power plant will include electro-hydraulic governors for both turbines. The first turbine is scheduled to go into service in September 1962, the second one four months later.

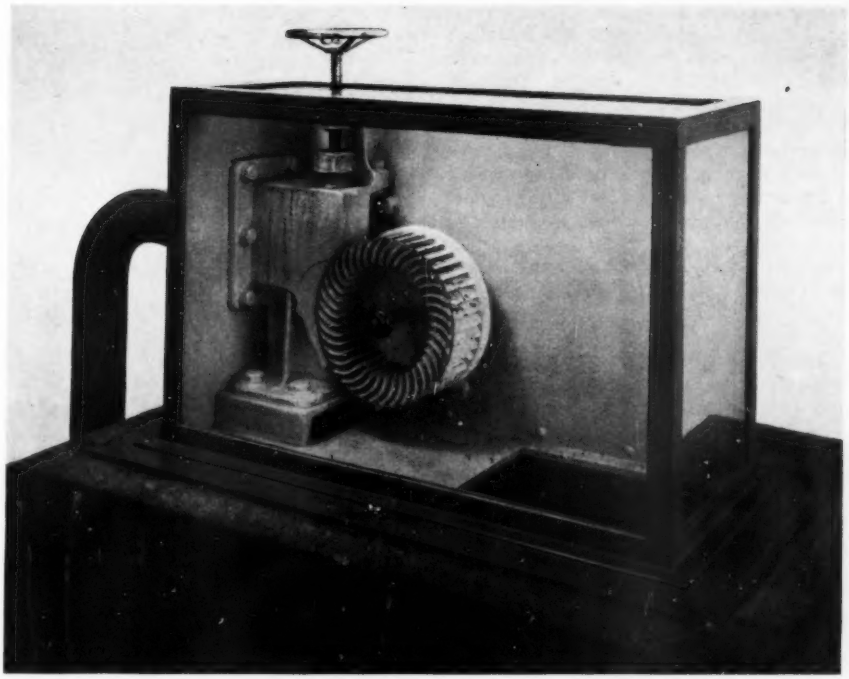


Fig. 1. Model of a Banki turbine in the German Museum, Munich. Runner diameter 8 in. (200 mm.). Photo: Deutsches Museum

The Cross-Flow Turbine

This article describes a type of water turbine which is being used extensively in small power stations, especially in Germany

By Dipl. Ing. Prof. L. A. HAIMERL, Munich-Pasing

THE inventor of the cross-flow turbine is the Australian engineer A. G. M. Michell, who obtained a patent for it in 1903. The turbine was later patented in Germany by the Hungarian Prof. Donat Banki, and became known more widely between 1917 and 1919 through a series of publications. A working model of the Banki turbine is exhibited in the German Museum in Munich (Fig. 1).

The present more widespread use of the cross-flow turbine is largely due to the efforts of the Ossberger concern, in Weissenburg, Bavaria, who added a number of original ideas to Michell's design, based on their own research work. The various stages of this steady development are covered by world patents. Today, numerous turbines throughout the world are operating on the cross-flow principle, and most of these (more than 5,000 so far) have been built by Ossberger.

The main characteristic of the cross-flow turbine is the broad water jet of rectangular cross-section which twice passes through the turbine blading at right angles to the shaft (Fig. 2). The water flows through the runner blading first from the periphery towards the centre, and then, after crossing the open centre space, from the inside outwards. This machine is therefore a turbine with two velocity stages, the water filling only part of the runner at any one time. As far as energy utilisation is concerned, the use of two velocity stages provides no immediate advantages; the arrangement represents, however, a very skilful design which removes the water in a simple manner after it has passed through the runner without producing any back pressure. The addition of a draft tube to the cross-flow turbine represents an interesting new development.

The machine is normally classed as an impulse or free-jet turbine. This classification is not strictly correct and is probably based on the fact that the original design was a true constant-pressure turbine. A sufficiently large gap was left between the nozzle and the runner to ensure that the jet entered the runner without any static pressure. There was also sufficient space

in the runner itself to allow the jet to expand freely sideways. During the passage through the first stage conditions were therefore essentially the same as in the much older Zuppinger free-jet turbine. The present design, in which the nozzle is shaped to follow the runner periphery closely, gives better results, however. At full or nearly full gate there is a slight positive pressure in the gap. This can readily be demonstrated by measuring the flow passing through the machine, with and without the runner, at constant head and gate; the flow is found to be greater if no runner is fitted in the turbine (experiments carried out by Prof. F. Euler at the Hagen Technical College). The deviation from the constant-pressure principle must of course be taken into account in closing the gap between nozzle and runner. It is only during the second passage of the water through the runner blading that the usual constant-pressure condition applies.

Theory: Unit Quantities

In dealing with the theory of the machine we simplify the vector diagrams (Figs. 2 and 3) as far as possible and leave for later consideration any variation from the conventional design.

We choose: $D_2=\frac{2}{3}D_1$, $\beta_1=150°$, $\beta_2=\beta_3=90°$, $\beta_4=180°-\beta_1=30°$.

The Euler turbine equation gives:

$$\eta gH=\underbrace{u_1\ v_{u1}-u_2\ v_{u2}}_{\text{First stage}}+\underbrace{u_3\ v_{u3}-u_4\ v_{u4}}_{\text{Second stage}}.$$

The inner vector diagrams 2 and 3 are identical; furthermore, $u_4=u_1$.

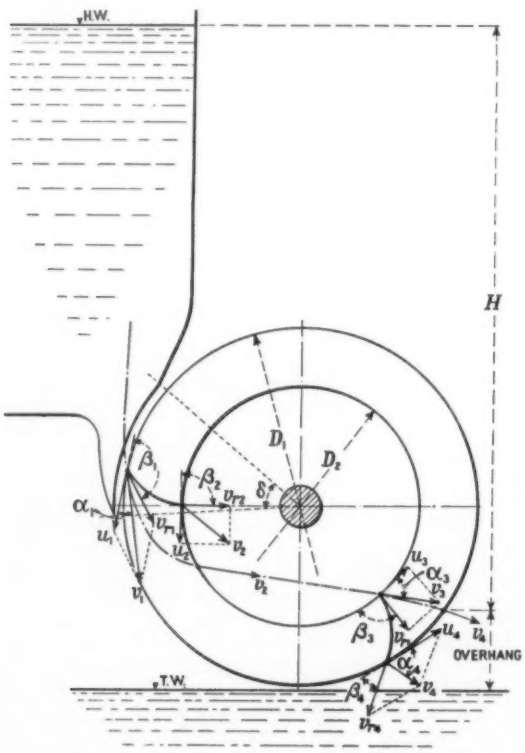


Fig. 2. Schematic diagram of cross-flow turbine

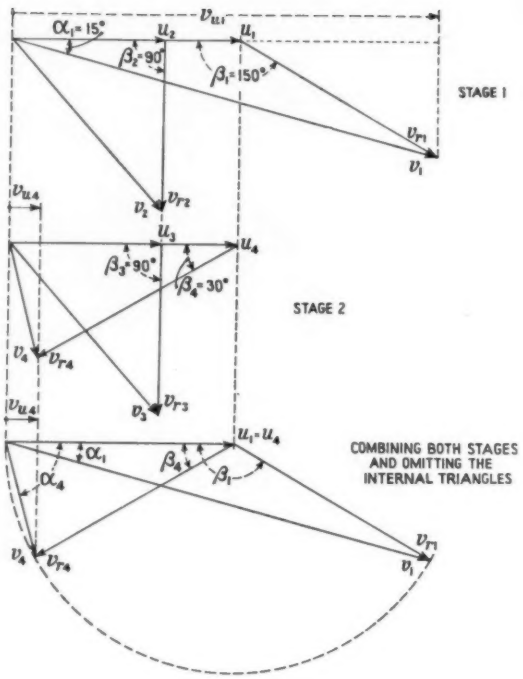


Fig. 3. Diagram of cross-flow turbine, neglecting shock losses

Therefore

$$\eta gH=u_1\ (v_{u1}-v_{u4}).$$

Using the geometrical relationships

$$v_{u1}=u_1-v_{r1}\cos\beta_1$$
$$v_{u4}=u_4-v_{r4}\cos\beta_4$$

where v_r is the relative velocity, and assuming that $v_{r1}=v_{r4}=u_1$ we have

$$\eta gH=u_1\ (u_1-u_1\cos\beta_1-u_1+u_1\cos\beta_4);$$

$\cos\beta_1=\cos 150°=-0{\cdot}866$; $\cos\beta_4=\cos 30°=+0{\cdot}866$ so that $\eta gH=1{\cdot}732\ u_1^2$.

For a head H of 1 m. the unit peripheral speed $u_1=\frac{u_1}{\sqrt{H}}$ is given by $u_1=\sqrt{\frac{\eta g}{1{\cdot}732}}$; taking as an average value for the hydraulic efficiency $\eta=0{\cdot}82$ we obtain $u_1=\sqrt{\frac{0{\cdot}82\times 9{\cdot}81}{1{\cdot}732}}=2{\cdot}16$ m./sec.

Unit speed $n_1'=u_1\frac{60}{\pi}=2{\cdot}16\times 19{\cdot}1$, so that

$$n_1'=41 \text{ r.p.m.}$$

The machine is therefore a slow-speed turbine. For turbines manufactured by Ossberger n_1' lies between 35 and 39 r.p.m., that it is in the range of values for Pelton turbines.

To determine the flow through the turbine we apply the continuity equation. If the arc over which the jet enters the runner is $\frac{1}{2}\ D_1\ \delta$ we have

$Q=v_{m_1}\ B_1\ \frac{1}{2}\ D_1\ \delta$ where $v_{m1}=v_{r1}\sin\beta_1=\frac{1}{2}\ u_1$ for $\beta_1=150°$

$$Q=\tfrac{1}{4}\ u_1\ \frac{B_1}{D_1}\ D_1^2\ \delta.$$

The unit flow Q_1' is $\frac{Q}{D_1^2\sqrt{H}}$ so that

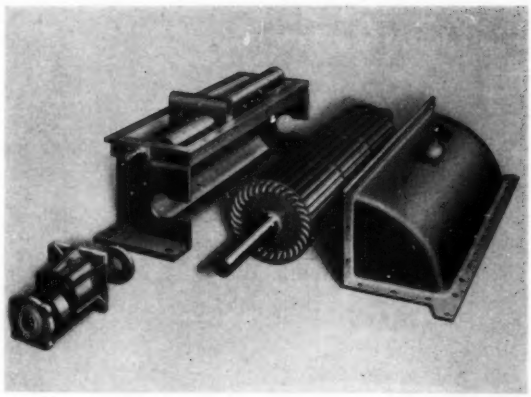


Fig. 4. Main parts of an Ossberger cross-flow turbine

$Q_t' = \frac{1}{4}\ u_t \frac{B_1}{D_1}\ \delta$. Taking the jet entry arc δ as 90° we have $\delta = \frac{1}{2}\ \pi$, and with $u_t = 2{\cdot}16$ m./sec.

$$Q_t' = 0{\cdot}85\ \frac{B_1}{D_1}.$$

B_1/D_1 is called the aspect ratio. For large flows, runners have been built with aspect ratios of up to 3·5. The cross-flow turbine is thus capable of passing a surprisingly large unit flow. Values for the Ossberger turbines agree well with the theoretical result above.

The specific speed (metric) $n_s = 3{\cdot}65\ n_t'\ \sqrt{Q_t'\eta}$. In the present case we have first the theoretical result

$$n_s = 3{\cdot}65 \times 41 \times \sqrt{0{\cdot}85\ \frac{B_1}{D_1}\ 0{\cdot}82} = 125\ \sqrt{\frac{B_1}{D_1}}.$$

Actual turbines whose characteristics differ in certain respects from the ideal ones give

$$n_s = (75\ \ldots\ 120)\ \sqrt{\frac{B_1}{D_1}}.$$

Reaction Effect in First Stage

This question can be answered by the so-called extended Bernoulli equation. With a relative exit velocity $v_{r2} = \frac{3}{4}\ u_1$ as required by the continuity equation for the conditions of Fig. 2 and Fig. 3 we have

$$h_1 - h_2 = \frac{u_1^2 - u_2^2}{2g} + \frac{v_{r2}^2 - v_{r1}^2}{2g} + h_{v1-2};$$

$$v_{r1} = u_1,\ v_{r2} = \tfrac{3}{4}\ u_1,\ u_2 = \frac{2}{3}\ u_1$$

so that

$$h_1 - h_2 = 0{\cdot}118\ u_1^2 + h_{v1-2}.$$

If all terms are referred to unit head $H = 1$ m. and if the specific friction loss in the first runner stage is estimated as

$$\rho_{1-2} = h_{v1-2}/H = 0{\cdot}035,$$

we have

$$\frac{h_1 - h_2}{H} = \frac{0{\cdot}118}{2g}\ u_t^2 + 0{\cdot}035;$$

with the theoretical value $u_t = 2{\cdot}16$ m./sec. we obtain

$$\frac{h_1 - h_2}{H} = 0{\cdot}063.$$

The pressure rise in the runner is therefore 6·3% of the available head. When v_{r2} is small, i.e. at small gate openings, $h_1 - h_2$ becomes zero and the turbine operates without reaction. This is borne out by experience, since the piling up of the water between nozzle and runner disappears as the jet flow is reduced.

The second stage operates truly at constant pressure since the pressures are balanced through those runner passages 3–4 which are not running full.

Power Ratio between the Two Stages

The momentum equation for each of the two stages gives $M_{1-2} = Q\ \frac{\gamma}{g}\ (R_1\ v_{u1} - R_2\ v_{u2})$; $M_{3-4} = Q\ \frac{\gamma}{g}\ (R_3\ v_{u3} - R_4\ v_{u4})$.

The power ratio between the two stages is denoted by ψ:

$$\psi = \frac{M_{1-2}}{M_{3-4}} = \frac{P_{1-2}}{P_{3-4}} = \frac{R_1\ v_{u1} - \frac{2}{3}\ R_1\ v_{u2}}{\frac{2}{3}\ R_1\ v_{u3} - R_1\ v_{u4}}$$

Using the values in Fig. 3 we obtain

$$\psi = 4{\cdot}6.$$

The first stage thus develops 4·6 times as much torque and power as the second stage.

Application of Cross-Flow Turbine

The cross-flow turbine has proved highly successful in small hydraulic power stations up to about 300 h.p. It covers a head range of 1 to 100 m. Because of the high unit flow rate, flows of up to 3 m.³/sec. can readily be achieved, provided the head is not too low. The turbine speed varies between 60 and 2,000 r.p.m. depending on runner diameter and head. This extensive range is very suitable for corn mills, saw mills, farm machinery, workshops, pumping installations and small electricity generating stations. When feeding into a transmission system it is preferable to use the very simple asynchronous alternator; this is excited from the electric system and automatically kept at

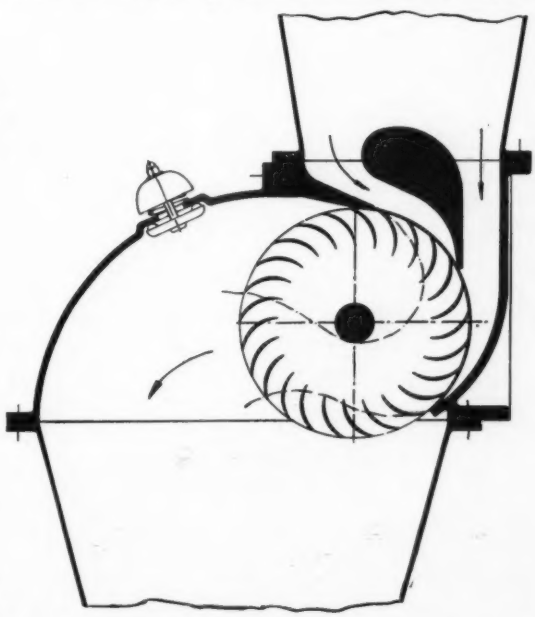


Fig. 5. Section through runner and gate of an Ossberger cross-flow turbine with draft tube

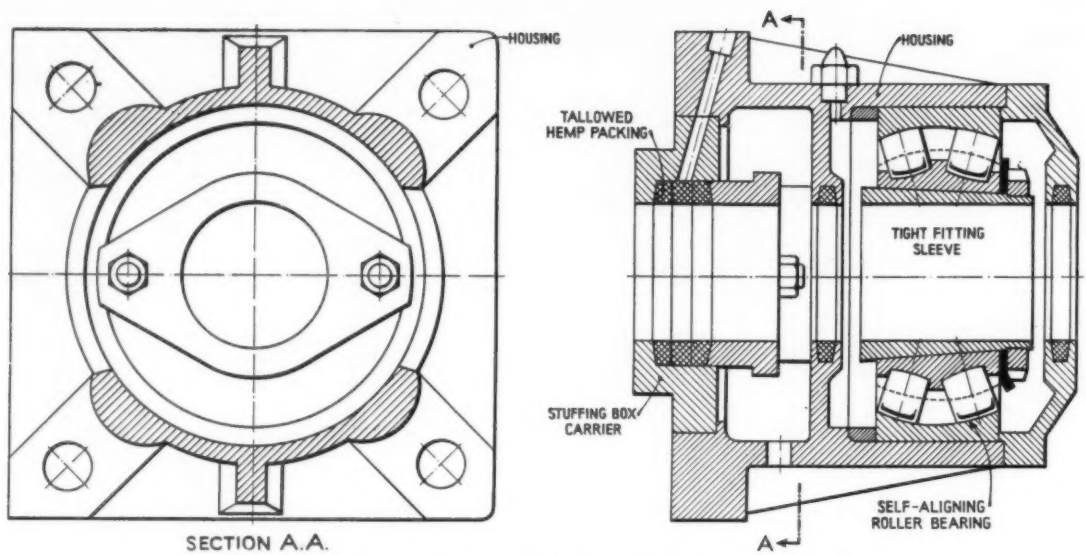


Fig. 6. Main bearing of an Ossberger turbine with draft tube

the correct speed so that no governor is required.

The specific speed which has already been referred to lies usually between 40 and 200 (metric), depending on the jet aspect ratio and the length of the jet entry arc. The aspect ratio can have a value up to breadth/width $=3$; at low heads this may even be increased to 3·5. The jet entry arc is between 90° and 120°; the present-day Ossberger turbines use a value of 120°. Comparing this range of specific speed with those of other turbines, the cross-flow turbine is seen to cover the entire range from the two-jet Pelton turbine up to the ordinary Francis runner. This long-felt gap between the expensive multi-jet Pelton turbine and the relatively slow Francis turbine is thus bridged very satisfactorily.

The runner sizes of the Ossberger turbines range from 8 in. to 24 in. (200–600 mm.); to simplify manufacture, sizes have been standardised in steps of 4 in.

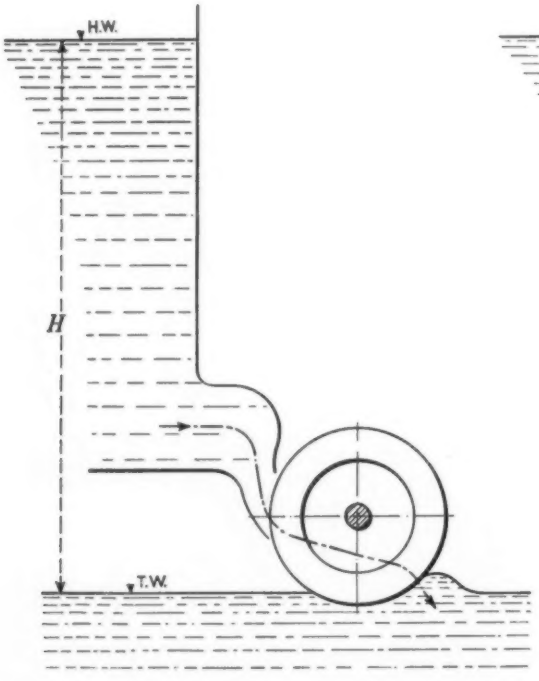


Fig. 7. Schematic arrangement of cross-flow turbine set at tailwater level

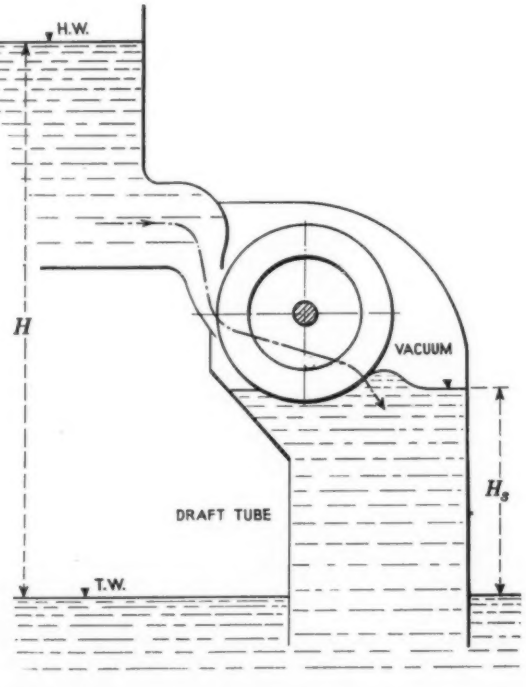


Fig. 8. Schematic arrangement of cross-flow turbine with draft tube

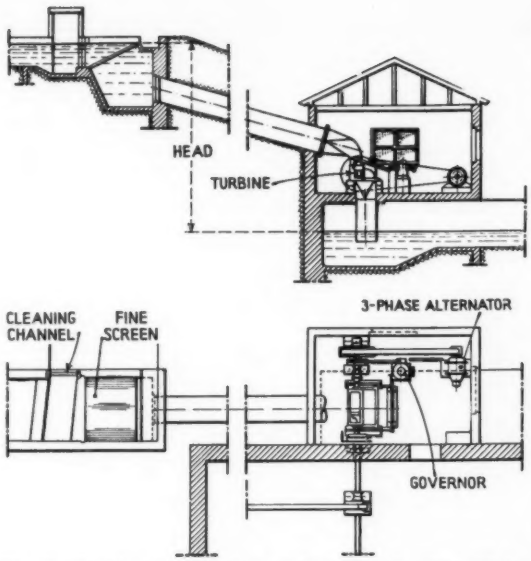


Fig. 9. Turbine installation with draft tube; H = *20 ft. (6 m.),* Q = *4–25 cusecs (117–700 lit. per sec.), maximum power 44·8 h.p. Fitted with governor and driving a three-phase alternator and a saw mill*

(100 mm.). Recent turbines have also included 32 in. (800 mm.) runners which can pass up to 15 cusecs (4 m.³/sec.).

Main Constructional Features

The main parts of the machine are the runner with shaft and bearing, the nozzle and gate with the water inlet, and the casing (Fig. 4). A characteristic of this turbine is the drum-shaped runner in which the blading is carried on a through shaft. This arrangement gives great mechanical strength to the runner, as well as sufficient stiffness to suppress all vibrations. The through shaft has no adverse effect on the flow of the water; during normal operation the water passes below the shaft and reaches the reverse entry point undisturbed. It is only during starting up and when running well below the normal operating speed that the jet touches the shaft; under normal circumstances these conditions only last for a very short time and are therefore of no practical importance.

The blades are carried at each end by circular discs provided with slots, and are assembled by arc welding. Between 26 and 30 blades are used, depending on the runner size; they are made from bright-drawn steel bar of the appropriate shape, thus combining high strength with hydraulically correct form. The blades are subject to very severe mechanical loads through centrifugal forces and the periodic impacts of the jet. A large safety margin against fatigue failure must obviously be the first consideration in design. Runners of greater width have one or two intermediate discs in order to reduce the unsupported blade length. All runners are balanced before assembling them into the turbine. The use of accurate bright-drawn blade profiles already provides a high degree of balance so that only minor corrections have to be made on the balancing machine.

The water flow into the turbine can be controlled and cut off completely by a gate which has a carefully designed flap to give the correct hydraulic shape; this is subdivided along the width of the machine. A division of the flow area in the ratio 1 : 2 has proved very advantageous for the operation of the machine, as will be shown later. Seen in the direction of flow, the guide passages are divided into two parts which are shaped so that the water is subjected to a continuous acceleration over a wide range of gate openings. The centre of rotation of the gate flap has been carefully chosen to achieve a large degree of balance between the hydraulic moments; a comparatively small governor can therefore be used. A good surface finish at the inside of the nozzle and at the gate edges allows the flow to be shut off by means of the gate when the machine is stopped. An additional valve is therefore unnecessary except in the case of very high-head installations, resulting in a reduction in total costs.

The main load-bearing parts of the housing are made from cast steel; the sides have suitable openings for the bearings while the nozzle with the water inlet is located at the top. The bearings are so arranged that they can be removed together with the turbine shaft without having to dismantle the heavy inlet bend or the nozzle itself. The casing also includes the cover which is fitted with an automatic vent valve

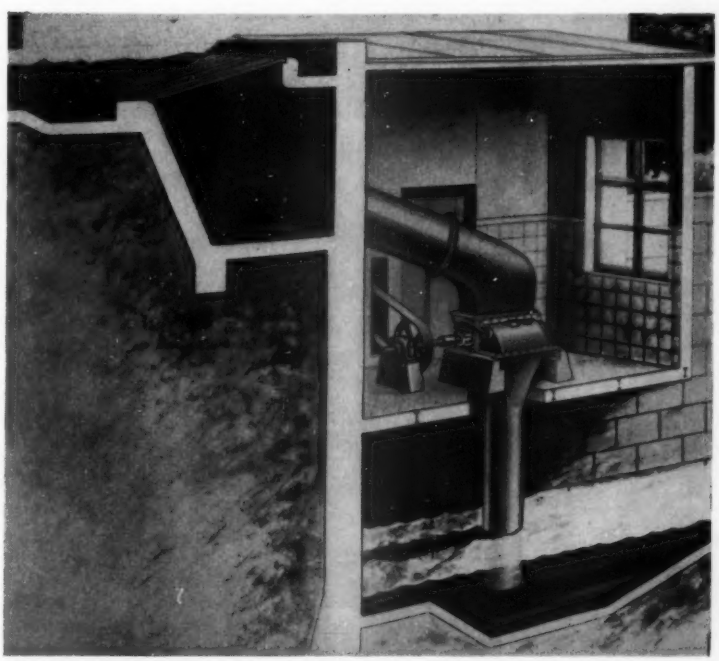


Fig. 10. Illustration of a draft-tube turbine for direct power generation

when the turbine operates with a draft tube (Fig. 5).

The turbine shaft is carried on both sides of the housing by heavy self-aligning roller bearings (Fig. 6). In most installations where a belt drive is used there is in addition a separate independent bearing, with heavy drives, so that the main turbine bearing is relieved of loads due to the belt or flywheel. In turbines fitted with a draft tube the bearing is combined with a stuffing box which has to seal against vacuum. The sealing material is a hemp packing impregnated with tallow. The roller bearings themselves only carry simple felt rings to prevent loss of grease.

In addition to the usual speed regulation, most installations also require some control over the flow and therefore the water level in the forebay. A simple arrangement of this type is the water-level regulator with a float which controls the turbine gate. This arrangement, usually called a "gate limiter," prevents too rapid utilisation and draw down of the forebay water in time of low run-off. If the control has to be operated over greater distances, it is advisable to employ an electrical system which is also available from Ossberger.

Cross-Flow Turbine with Draft Tube

The draft tube has the important function of utilising the difference in level between runner and tailwater. If the draft tube is omitted, the net usable head is reduced by the height of the turbine setting. The loss due to this cause, especially in the case of low heads, may reach a proportion which could not be tolerated. There are two possibilities of avoiding these losses. The turbine can be arranged immediately above the tailwater (Fig. 7), or alternatively it is set at a more convenient height and a draft tube added to the completely sealed casing (Fig. 8). When the turbine is running, the air inside the casing is swept out together with the water so that a vacuum is formed and a suction column rises in the draft tube due to the external atmospheric pressure. This negative pressure can be so large that the water level reaches the runner, causing the latter to "wade." Vent valves operated by a float, or a spring-loaded valve, allow the water level in the housing to be controlled and kept close to the "wading limit." An interesting fact derived both from practical experience and from power measurements in the laboratory is that the cross-flow turbine is relatively insensitive to "wading." This result has been confirmed on numerous occasions, particularly at full load.

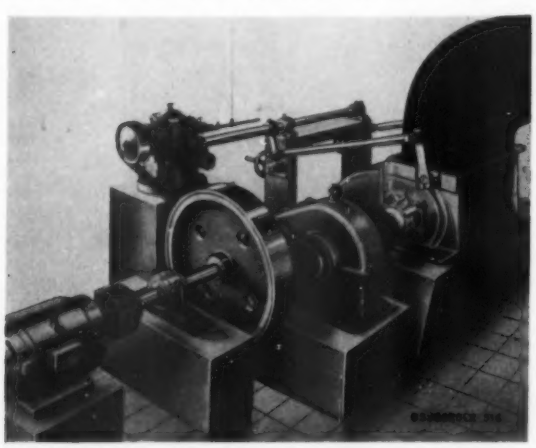


Fig. 11. Generating station with draft-tube turbine and governor. H=18¾ ft. (5·65 m.), Q=19 cusecs (545 lit. per sec.). Maximum power 33 h.p.

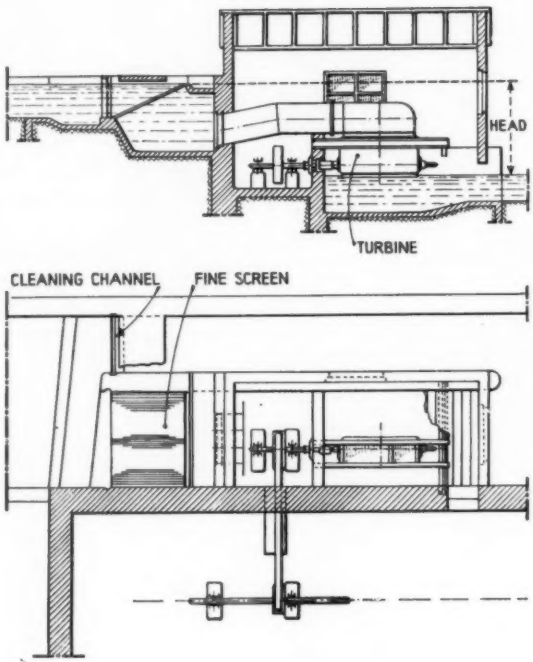


Fig. 12. Low-setting turbine with belt drive and hand control

We shall consider an ideal draft tube in which the effects of air in the water and flow losses are neglected. A small amount of runner wading is permitted so that the height-of-setting losses are completely avoided. The turbines compared in Fig. 7 and Fig. 8 are entirely equivalent as far as power output is concerned, assuming ideal conditions. The advantage of the turbine with the draft tube, however, is that the higher setting gives more freedom in the general arrangement of the plant and the power transmission than with an open discharge turbine, which is cheaper but has to be set immediately above the tailwater, a location that is often somewhat inaccessible. In most cases it is sufficient to set the draft-tube turbines 5–7 ft. (1·5–2 m.) above the tailwater level.

Arrangement of Cross-Flow Turbines

We shall now describe a number of power stations with cross-flow turbines which were supplied by Ossberger. Fig. 9 shows a power station for a sawmill in which the turbine, complete with alternator and governor, is set above flood level and readily accessible. Part of the energy is transmitted through a direct drive to the saw; after working hours this drive is disconnected by a clutch while the alternator remains in operation. The heavy flywheel is doubly supported so that the turbine bearings have to carry only the runner weight and the hydraulic forces. The water is supplied from the headrace through steel pipes and is shut off solely by the turbine gate.

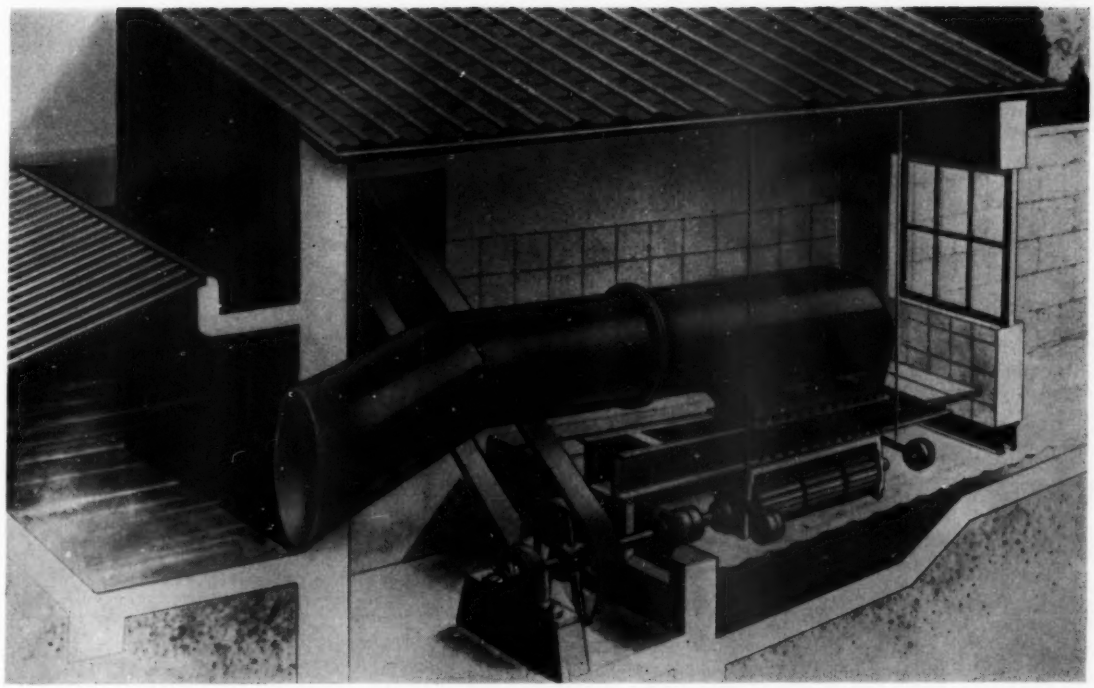


Fig. 13. Illustration of a low-setting turbine with belt drive. Manual control by wire ropes

A turbine with draft tube, used for direct power transmission only, is shown in Fig. 10. The load is essentially constant so that the governor could be omitted; manual control through steel cables is sufficient in this case.

More details are shown in Fig. 11, which represents a hydraulic power station of modern design. The draft-tube turbine drives a three-phase alternator through an oil-filled speed-increasing spur gear. A heavy flywheel is mounted on the alternator shaft to improve governing during sudden load changes. The illustration shows the oil governor together with the governor shaft and frame; there is also provision for manual operation. The turbine gate, as in the case of the other applications, is subdivided in the ratio 2 : 1; two separate operating linkages were required, but the latest model, shown in Fig. 14, operates on a single common linkage.

The examples illustrated in Figs. 12 and 13 will be of interest where a turbine can conveniently be arranged at a low setting. The height above tailwater is so small, even when the tailwater is low, that it can readily be accepted. If the tailwater should rise appreciably, the wading limit is, however, soon exceeded. The low setting of the belt drive requires a wall stuffing box so that the drive pit is kept dry. In order to prevent the ingress of water under all conditions, it is advisable to provide the drive pit with a steel lining.

Fig. 14 shows a complete generating set which was exhibited at the 1959 Hanover Fair. Turbine, gearing, alternator and governor are mounted on a common welded frame. This considerably simplifies the installation of the equipment—a point of importance in view of the present shortage of experienced erectors. Fig. 14 also shows the latest type of turbine gate control. The two ends of the divided gate are operated through a common lever; the connecting rod acts as a balance beam and opens the gate in accordance with the water flow.

Operation

A most valuable feature of the cross-flow turbine is the favourable shape of its efficiency curve, which is further improved by using a divided gate. The long flat peak and the low no-load flow are specially important for small power stations, where frequently only a single turbine is installed and the water flow varies between wide limits. In such cases the maxi-

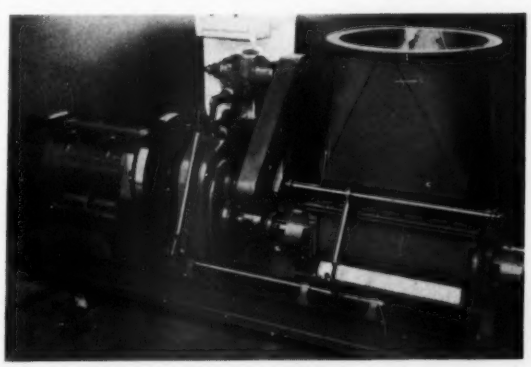


Fig. 14. Complete Ossberger turbine set on common frame. H=*17 ft. (5 m.),* Q=*13 cusecs (365 lit. per sec.), power=12 kW, turbine speed 270 r.p.m., alternator speed 1,500 r.p.m.*

mum efficiency is a secondary consideration. While it is true that the Francis turbine has a better peak efficiency (shown dotted in Fig. 15), the peak is relatively narrow so that the efficiency drops rapidly at low flow rates. In power stations with several machines, preferably of different size, the use of Francis turbines is of course fully justified, since they can be stopped and started to suit the water flow. This consideration does not apply to small stations, however.

In order to explain the cause of the flat-topped efficiency curve of modern cross-flow turbines, let us first consider an undivided turbine such as could be used for mainly full-load duty (Fig. 1). Dividing it into regions of 1/3 and 2/3 full load, we obtain curves with correspondingly shortened abscissae; their envelope is the idealised efficiency curve for a cross-flow turbine with a gate divided in the ratio 2 : 1 (Fig. 16). In an actual turbine the efficiencies in the 1/3 and 2/3 gate ranges are somewhat lower than shown above, since the losses due to friction, vortices, gap losses and windage become more pronounced at part load. It is interesting to note that the drops near each transition point are smoothed out so that they can in practice be neglected, resulting in the smooth curve of Fig. 15. The maximum efficiency of 82% is an average value which is obtained at approximately 70% gate. Good cross-flow turbines of large size and output achieve a maximum efficiency of 86%.

The Kaplan turbine also has a very flat efficiency curve which is actually higher than that of the cross-flow turbine. It must not be overlooked, however, that this high-specific-speed turbine is much more expensive than the cross-flow turbine, as is the civil-engineering work involved. Furthermore, because of its high specific speed it can only be used where low heads are combined with high flow rates and a high turbine speed.

Comparison between Cross-Flow and Francis Turbine

During starting the cross-flow turbine behaves similarly to a Francis turbine of moderate specific speed. The runaway speed reaches 1·8 to 2 times the normal operating speed.

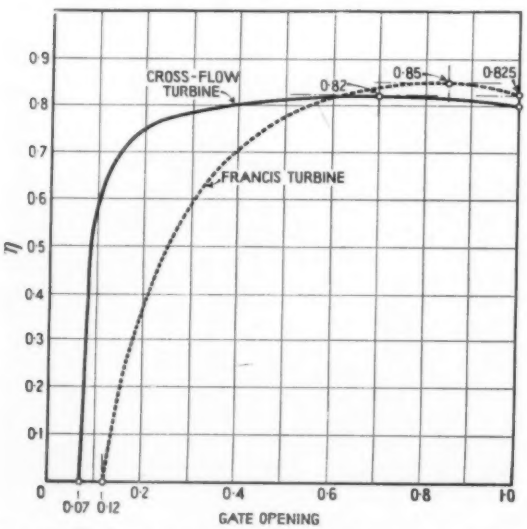


Fig. 15. Efficiency curve of a cross-flow turbine with divided gate. The efficiency curve of a Francis turbine of similar size is shown dotted for comparison

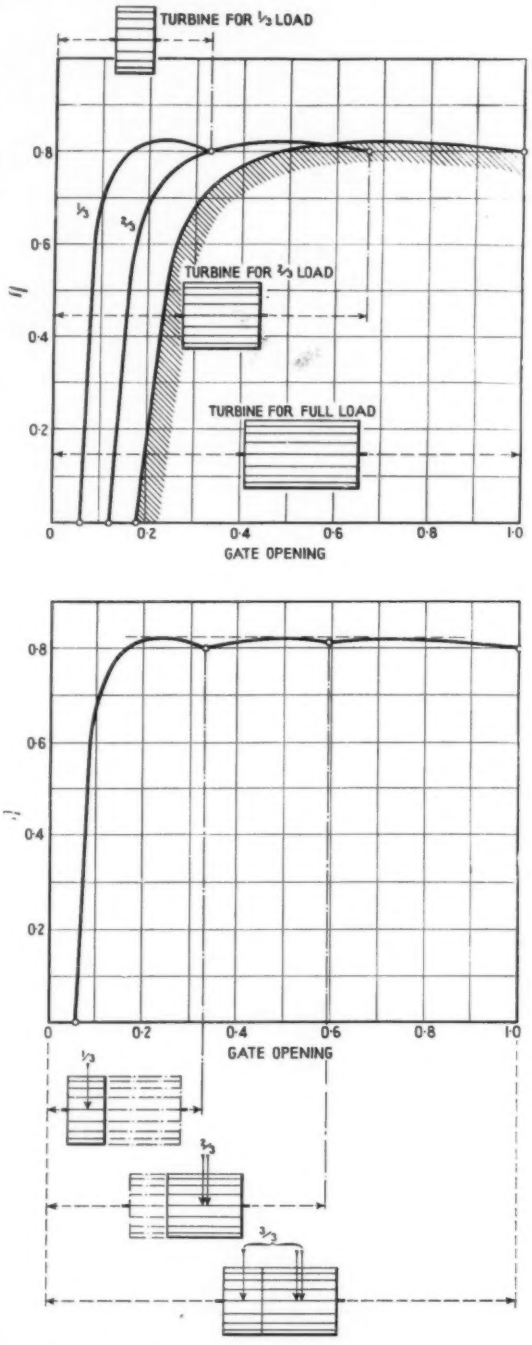
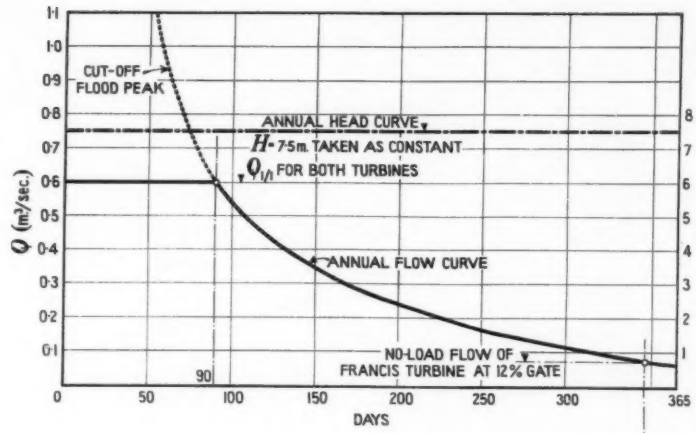


Fig. 16. Efficiency curve of a cross-flow turbine at full-load operation (shaded). Two further curves for 1/3 and 2/3 load derived from it by shortening the abscissae. Lower diagram: combining the three curves into a single overall efficiency curve. Ideal cross-flow turbine with divided gate



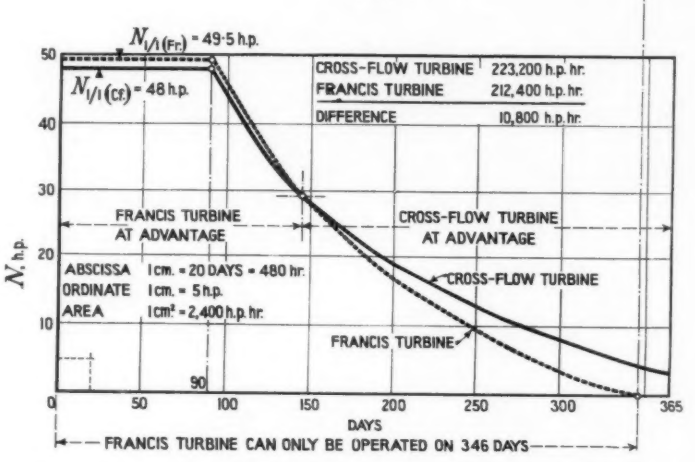

N1/1(Fr.) = 49·5 h.p.
N1/1(cf) = 48 h.p.
CROSS-FLOW TURBINE 223,200 h.p. hr.
FRANCIS TURBINE 212,400 h.p. hr.
DIFFERENCE 10,800 h.p. hr.
FRANCIS TURBINE AT ADVANTAGE
CROSS-FLOW TURBINE AT ADVANTAGE
ABSCISSA 1 cm. = 20 DAYS = 480 hr.
ORDINATE 1 cm. = 5 h.p.
AREA 1 cm² = 2,400 h.p. hr.
CROSS-FLOW TURBINE
FRANCIS TURBINE
N, h.p.
DAYS
FRANCIS TURBINE CAN ONLY BE OPERATED ON 346 DAYS

Fig. 17 (above). Annual flow and head curves for a small power station

Fig. 18 (below). Annual power and energy curves for cross-flow turbine

It often happens that a Francis turbine competes directly with a cross-flow turbine, and it is interesting to compare the two machines on the basis of a particular application. In order to provide a fair comparison it is necessary for the initial conditions to be equivalent. This means that both machines are similar in size and specific speed, are made to the same quality of manufacture, are in the same running condition and are provided with the appropriate civil-engineering setting. The two efficiency curves shown in Fig. 15 can be used as the basis of comparison. To give a true picture, one of the usual annual flow curves shown in Fig. 17 can be used as statistical data. The head $H=7{\cdot}5$ m. (30 ft.) is taken as constant. Under these conditions we can draw for both turbines the annual power output curves (Fig. 18) in accordance with the usual equation

$$\text{h.p.}_{\text{metric}}=\frac{Q\,\gamma\,H\,\eta}{75}$$

so that in our case

$$\text{h.p.}=\frac{Q\times 1000\times 7{\cdot}5\times\eta}{75}=100\;Q\;\eta$$

The annual energy utilisation in horsepower-hours, which is a true economic and financial figure and is therefore more important for comparing the two machines than efficiency by itself, is given by

$$E=24\int_0^{365}\text{h.p.}\;dt\;\text{(metric)}$$

The planimetric integration of the two diagrams gives the annual energies as:
Cross-flow turbine, 223,200 h.p. hours; Francis turbine, 212,400 h.p. hours; i.e. a gain of 10,800 h.p. hours.

While the increased output may appear to be rather insignificant, it represents a real gain; with steeper flow curves the advantage of the cross-flow turbine would be even more pronounced.

This calculation of the annual energy was based on the turbine flow rate available over three months, i.e. approximately 90 days; in this example it was 0·6 m.³/sec. Alternatively, the annual energy output may also be based on the optimum efficiency which is kept constant for both turbines during three months or 90 days. This method was discussed by the author in an article in the *Deutsche Müller Zeitung*, 1956. No. 17.

As far as operation is concerned, the cross-flow turbine has the further advantage that there is less chance of blockage due to leaves, grass, or ice than in the case of a narrow Francis turbine. If the drum runner should ever happen to become blocked at any one point, the impact of the jet from the opposite direction half a revolution later would rapidly clear the obstruction, assisted by the centrifugal force.

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Expandite Limited. The Technical Service Department of this firm have issued a pamphlet which touches on the complete range of Expandite products used by the civil-engineering, building and other industries.

Fig. 9. Panoramic view of the project taken early in 1959. At this time

Três Marias Dam

This key project for a major power and reclamation development in Brazil is a joint undertaking by Comissão do Vale do São Francisco and Centrais Elétricas de Minas Gerais S.A. This article discusses the design of the civil works

PART TWO

THE arrangement of the different structures of the project, as shown before, was dictated mainly by foundation conditions and the availability of local construction materials. In this way every effort was made to minimise the volume of concrete which proved to be very expensive at the site, and to utilise local materials to the maximum extent. The final layout resulted in an earthfill dam extending completely across the valley, a power plant on the right bank at the downstream toe, a gated open-channel spillway on the right abutment and a set of navigation locks and access channels on the left bank (Fig. 10).

The difficult geological conditions at the dam site, with the firm rock line on the right bank rising little above stream-bed level, caused the main question during preliminary layout studies to be concerned with finding the best way of conveying the water to the power house. Three alternatives were considered:

(*a*) through 8 concrete-encased steel penstocks;

(*b*) through 8 tunnels to be driven farther out into the abutment and

(*c*) by means of 8 syphon tunnels, dipping enough to get sufficient rock cover.

The first solution was finally adopted, based on careful cost estimates and practical considerations. As can be seen in Fig. 11, this resulted in easier construction, the concrete structures being set on the same abutment, near to each other, thus favouring the rapid transportation and placing of the concrete. The conduits, set low in sound rock, would allow the diversion of the water during the last two flood seasons before filling the reservoir.

The Dam

The embankment will consist of an impervious rolled earthfill, resting mostly on a thick blanket of overburden, with a trapezoidal section divided into three zones. The central core will receive the most impervious clays (CL type), the upstream shell impervious silts and clays of the CL and ML types, and the downstream shell random materials from the borrow areas and excavations. The side slopes of the dam are 2·5 : 1, 3 : 1, and 4 : 1 upstream, and 2 : 1, 2·5 : 1, and 3·5 : 1 downstream. Berms having a width of 3·0 m. are provided on the slopes, one on the upstream face and two on the downstream face.

about 3 million cu. m. of earthfill had been placed on the left embankment

The internal drainage system of the dam consists of a vertical sand drain connected below to a horizontal sand blanket extending to the toe of the dam; both are 0·8 m. thick and are made of clean fine sand. The dam, when finished, will be about 2,600 m. along the crest and will have a maximum height of about 70 m. above the stream bed. The crest, 10 m. wide, will be set at El. 572·0 with a minimum of 2·5 m. of freeboard over the maximum reservoir level of 569·50 m. at design flood, or 4 m. freeboard over the normal operating reservoir level of 568·0 m. At the central section of the valley, where the dam will be significantly higher, a camber was provided to compensate foundation and embankment settlements; the top of the dam in this section is at El. 573 m. The upstream face will be protected by 1·0 m. of riprap dumped on a 0·4 m. thick sand-filter blanket; below El. 541 the slope will be faced by 0·3 m. of crushed rock, spalls and quarry waste. The downstream face will be covered by 0·4 m. of top soil and sodded. Sections through the dam are shown in Fig. 12.

Various conditions of stability were investigated to determine the safety of the embankment during construction and during operation of the reservoir. The most critical conditions were found to be:—

Upstream region:

(*a*) during or soon after construction of the dam.

(*b*) after completion of the dam and filling of the reservoir, and when reservoir level is suddenly drawn down.

(*c*) steady state condition with full reservoir.

Downstream region:

(*a*) during or soon after construction.

(*b*) steady state condition with full reservoir.

Rapid drawdown was assumed to occur from El. 566 m. to El. 550 m. and would probably extend over a period of six months minimum (the term rapid for this drawdown is relative and must be tied directly to the coefficient of permeability of the local clays which is extremely small). For the analysis involving rapid drawdown two approaches were considered:

Method A: In the calculations the resisting forces were based on buoyant unit weights below El. 566 and saturated unit weights above; the driving forces were based on saturated unit weights above El. 550 and buoyant unit weights below.

Method B: The segment of the embankment formed by the trace of the trial circle was considered as a free body, with all external forces acting on this free body taken into account; the normal and tangential forces were computed using saturated unit weights and the uplift forces, due to pore-water pressures along the failure plane, estimated by flownet.

The conditions mentioned above were applied to chosen cross sections, and slip-circle analyses were made employing the appropriate soil parameters. The range of values for the soil parameters were:

Moist unit weight=1·86 tons per cu. m.
Saturated unit weight=2·0 tons per cu. m.
Buoyant unit weight=1·0 tons per cu. m.
$\emptyset$=14 to 25°; C=0 to 10 tons per sq. m.
and for the rock:
Moist unit weight= 1·60 tons per cu. m.
Buoyant unit weight=0·96 tons per cu. m.
$\emptyset$=35°; C=0

For the most critical conditions (drawdown), the soil parameters were:

$\emptyset$=25° and C=0 from S; saturated tests, for method *A*.

$\emptyset$=15° and C=9 tons per sq. m. from Qc, saturated, tests, for method *B*.

The smallest safety factors found were:

1·2 for the upstream region on the river section after rapid drawdown, and 1·15 also for the upstream region after rapid drawdown using a shallow trial circle (the area limited by the circle comprised a rock

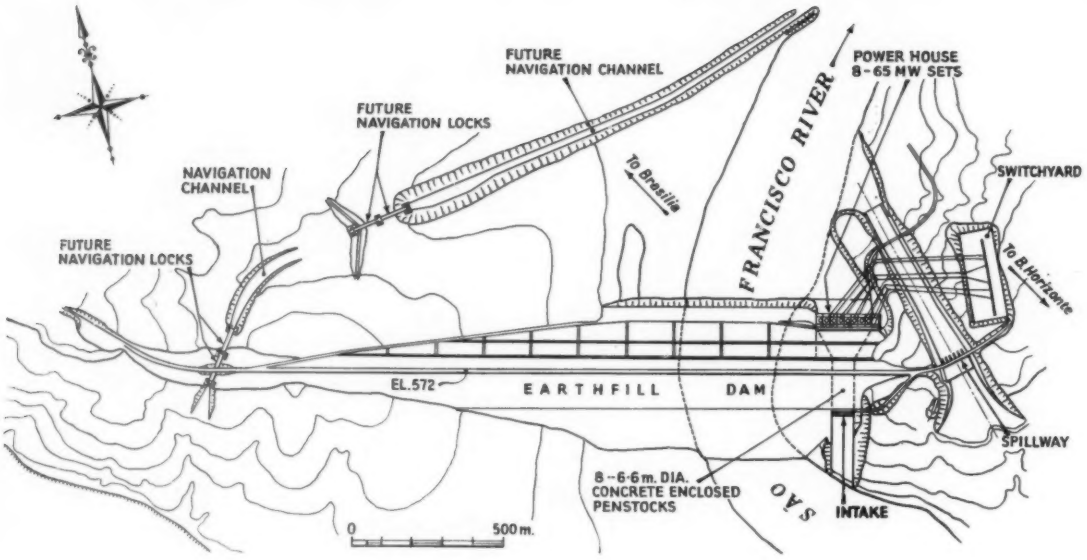


Fig. 10. Plan of the Três Marias dam and power station

section significantly bigger). In both cases method *A* was utilised.

During the design phase the most difficult problems to tackle were:

(*a*) Protection against underseepage in critical areas of the foundation, which called for:—

(1) a cut-off made of compacted clay-filled trench in the full extension of dam foundation, in the right abutment, and also in the flood-plain area.

(2) a grout curtain on solid rock, underneath the cut-off and across the river channel.

(3) construction on the river channel of a row of 6 in. diameter vertical relief wells, drilled 9 m. deep and 6 m. apart and connected to the internal drainage system of the dam.

(*b*) The very unstable condition of the waterlogged silts at the flood plain if surcharged by the dam weight; it was found advisable to remove completely such material down to rock, and this implied an excavation of about 850,000 cu. m. of material.

(*c*) Prevention against excessive settlement in the area above the flood plain between elevations 520 m. and 540 m.; the first 2 m. on the top loose clays were removed and re-used elsewhere in the fill.

Intake and Conduit Structures

The intake structure, which measures 72·2 m. long and 62 m. high, is to be located, as well as the power house, farther into the embankment in order to minimise the length of the penstocks. It is a reinforced-concrete structure with rounded conduit inlets measuring 4·5 m. × 8·5 m. at the gate slot. The base is set low into sound rock with the sill at El. 511, i.e., only 3 m. above river bed. Each conduit intake will be controlled by one fixed-wheel gate operated by an individually controlled hoist of 125 tons capacity, mounted on top of the structure at El. 572. At the entrance, the conduits and turbines will be protected by sets of steel trash-racks with a spacing of 5½ in. (14 cm.) between each pair of vertical bars. A vertical slot, upstream of the main slot, will accommodate a bulkhead gate.

A 55-ton gantry crane, travelling along the entire length of the structure will be provided to handle the gates and hoisting machinery for servicing. Access to the intake, well out in the pool, will consist partly of an earthfill resting on the right abutment and partly of a steel truss bridge. The intake will be rendered independent of the conduit structure by a vertical contraction joint located at the end of the transition and at the beginning of the steel penstocks.

Conduits to serve the power house consist of steel pipes 6·60 m. in diameter encased in heavily reinforced concrete. The structure is solidly built on firm rock. The tubes will have a parallel alignment for 160 m., from which they will diverge in separate trenches in order to enter the power house at the proper positions.

The horizontal sand blanket over the concrete conduit encasement will be thickened from 0·8 m. to 1·5 m., its function in this area being mostly to collect any seepage between concrete and rock or concrete and earthfill.

The penstocks will be made of Firebox A 283 and A 285 grade C type steel with a maximum allowable stress of 9,600 kg. per sq. cm. The design called for steel plates 1 in. thick in the first 200 m. and 1⅛ in. thick in the final stretch, which varies in length from 93·58 m. to 104·60 m., depending on the position of the tube.

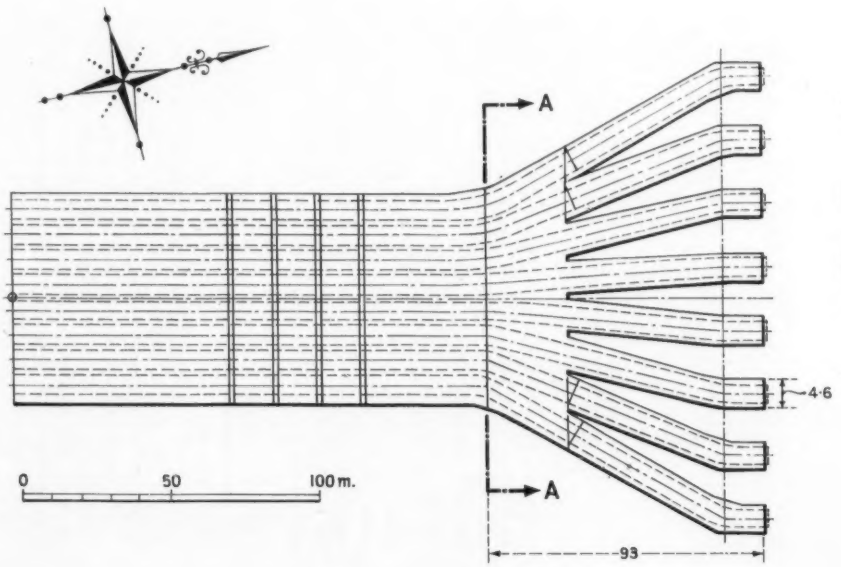
The design assumptions were:—

For the steel lining:

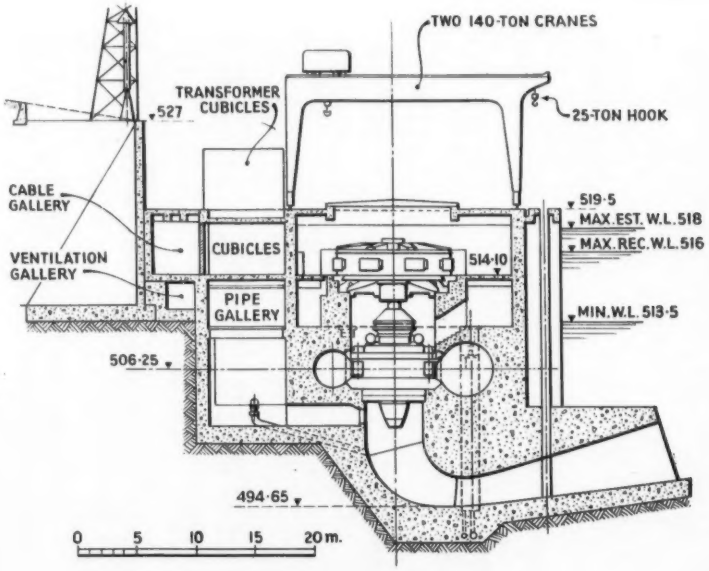
1. To resist internal hydrostatic head with reservoir at maximum level for maximum allowable stresses and allowing the steel to be overstressed with additional waterhammer pressures.
2. To avoid collapse from full external hydrostatic load when the gates close off all flow.
3. Field joints will be butt-welded with no provision for expansion.

For the concrete encasement:

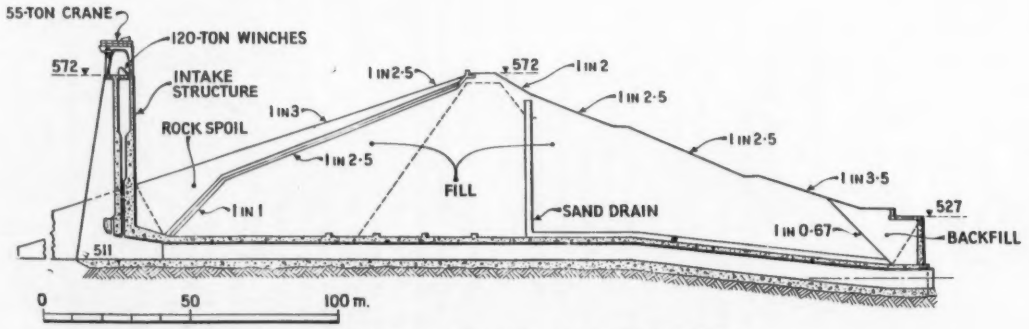
1. To resist all external forces: weight of fill (in



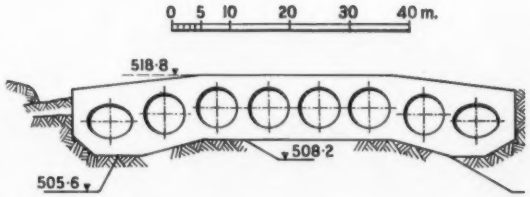
PLAN OF ENCASED CONDUITS



TRANSVERSE SECTION THROUGH POWER HOUSE



SECTION THROUGH INTAKE AND CONDUITS



SECTION A.A.

Fig. 11. Arrangement of the encased conduits passing through the dam, together with a section through the power house

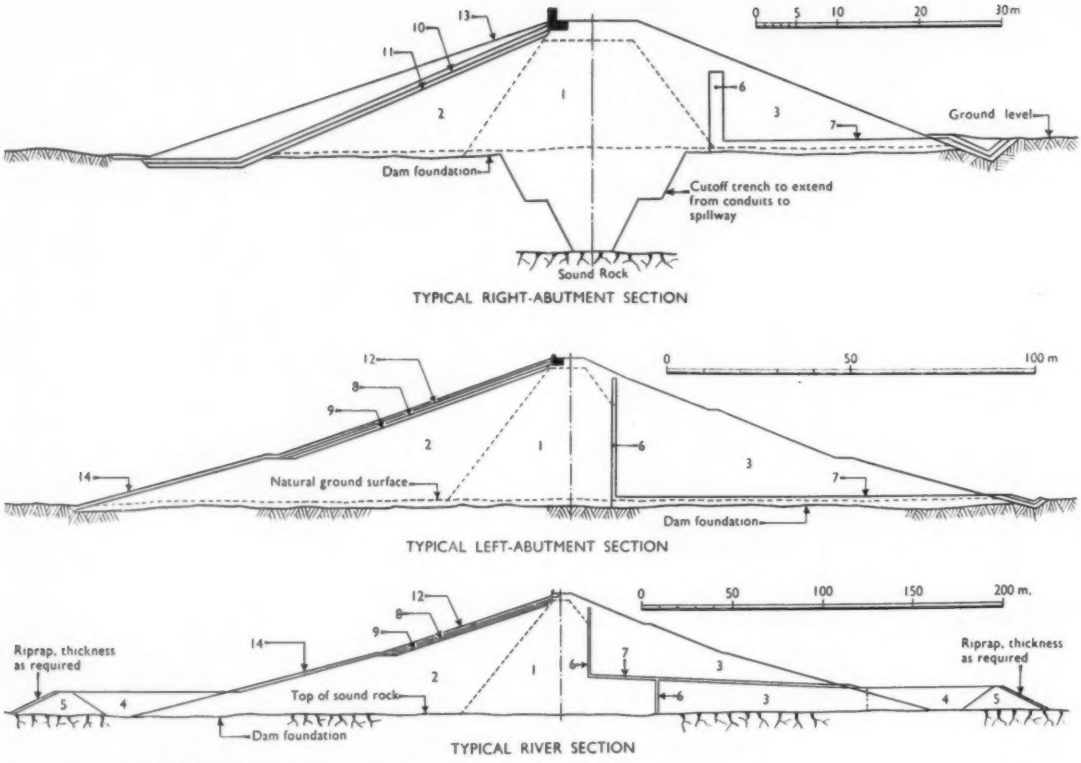


Fig. 12. Typical dam sections

1. CL Type clay wetter than optimum water content
2. CL Type clay at or slightly below optimum water content
3. Random fill
4. Berm—waste material
5. Cofferdam
6. Vertical sand drain—0·80 m. thick
7. Horizontal sand drain—0.80 m. thick
8. Coarse filter for riprap—0.40 m. thick
9. Fine filter for riprap—0·30 m. thick
10. Coarse filter for rockfill—0·60 m. thick
11. Fine filter for rockfill—0·40 m. thick
12. Riprap—0·90 m. thick
13. Rockfill—Larger sizes of the select rockfill to be placed on the outer slopes between top of dam & El.541.0
14. Rock spalls—0·30 m. thick

saturated and submerged state), lateral earth pressures, and uniform foundation pressure.

2. Loading conditions were:
   (*a*) Full reservoir, all conduits empty.
   (*b*) Full reservoir, all conduits full.
   (*c*) Empty reservoir, all conduits empty.
   (*d*) Full reservoir, several combinations of full and empty conduits.
3. The structure was analysed at each transverse section as a continuous frame with round haunches on beams and columns.

Spillway

The spillway is located on the right bank and consists of an approach channel, a gate-controlled ogee-shaped weir placed on sound rock at the top of the ridge, followed by an inclined trapezoidal channel that conveys the water to a point of the river 350 m. downstream of the power house, after having its energy dissipated through a conveniently located flip bucket. Release of water from the reservoir will be controlled by seven radial gates 11 m. wide by 13·7 m. high, each gate having individual hoisting machinery mounted on top of 2·5 m. thick concrete piers. The concrete-lined channel will be about 550 m. long and 60 m. wide, dropping from El. 554·30 at the spillway crest to El. 508·60 at the bottom of the spillway basin, and to approximately El. 508 in the river channel at the outlet. The spillway capacity was determined by routing through the reservoir an inflow flood, occurring each 10,000 years, with a duration of 72 hours and a peak of 23,400 cu. m. per sec.; the maximum resulting outflow was 8,700 cu. m. per sec. for which the spillway was designed. The reservoir was found to reach a maximum (El. 569·2) with all the gates open and 569·5 m. with one gate in the closed position. The channel spillway was subject to considerable model testing in order to find good hydraulic conditions and the most economic dimensioning. Two models were built at scales of 1 : 100 and 1 : 75, and the following tests carried out:

(*a*) on the approach channel area: investigations to obtain tranquil and uniform entrance flow with a view to reducing the excavations to a minimum.

(*b*) for the weir: check of the pressures across the spillway crest, setting of the gate trunnion, shaping of the piers and calibration of the discharges for different gate openings.

(*c*) for the given chute profile: an alignment was sought for the transition walls that would result in uniform flow patterns, without erosion of the concrete.

(*d*) on the downstream end of the channel: 21 trials were made to obtain a suitable flip-bucket design to prevent any major scouring of the river banks or damage to the downstream end of the structure.

(To be continued)

Norway's Hydro-Electric Power and Industries

An economic study of Norway's power potentialities and development, and of the industries which the country's cheap power has brought into being

PART TWO

HOW does Norway dispose of all her power? In 1957 about 35% of it was distributed to domestic, agricultural and business consumers, about 8·5% to the pulp and paper industry, and about 11% to the mining and engineering industries, while the largest amount, about 43% or nearly 10,000 million kWh, was distributed to the electro-chemical and metallurgical industries. Curiously enough for a country so richly endowed with power her railways are not yet fully electrified. They and tramways were together credited with only about 1·5% of the total in that year.

The following are some of the more important products of the electro-chemical and metallurgical industries in Norway:—

Metals	*Chemicals*
Ferro-alloys, including:—	A wide range of nitrogenous fertilisers, based on ammonia, including:—
Ferro-silicon (45% Silicon)	Nitrate of lime
Ferro-manganese	Ammonium nitrate limestone
Ferro-chrome	Sodium nitrate, etc.
Silico-manganese	Urea
Aluminium	Calcium carbide
Nickel	Calcium cyanamide
Copper	Dicyandiamide
Zinc	Superphosphates
Iron and steel	Hydrogen
Magnesium	"Heavy water"
Silicon carbide	Chlorine
Rockwool	Chlorates, sodium potassium
Cadmium	Caustic soda
Various precious metals in small quantities	Plastic raw and finished materials
	Various pure inert gases

As their name implies, electro-chemical and metallurgical products require a large amount of power to produce. The approximate amounts required by some of them per metric ton are given below in kWh:—

Aluminium	17,000	Electrolytic zinc ...	4,150
Magnesium (from sea water)	16,000	Calcium carbide ...	4,000
		Electrolytic nickel ...	3,750
The pure nitrogen content of various forms of fertilisers	14,000	Chlorine	3,750
		Ferro-manganese (standard)	3,500
Ferro-silicon (75%)	10,000	Caustic soda (100%)	3,500
Sodium chlorate ...	6,250	Electric pig iron ...	3,000

If one considers that a difference in power costs of, say, ¾d. per unit between the United Kingdom and Norway represents, for example, a difference of about £50 a ton in the manufacturing cost of aluminium selling for about £180 a ton the advantages of electro-metallurgical manufacture in Norway becomes fully apparent.

Ferro-Alloys

Norway's electro-metallurgical products that achieve the highest aggregate value are her ferro-alloys. These are divided roughly into two groups, namely, ferro-silicon (45% silicon), on the one hand, and on the other, ferro-manganese, ferro-chrome, silico-manganese, etc. Production of these two groups (Fig. 3) has expanded from about 40,000 tons and 93,000 tons before the war to 145,000 tons and 169,000 tons, respectively, in 1957. Owing to the world depression, production in 1958 fell to about 120,000 and 130,000 tons, but the industry's capacity for the two groups is put at 175,000 tons and 180,000 tons respectively. Exports in 1958 were provisionally valued at £3·6 million (£4·6 million) and £7·1 million (£12 million) respectively (1957 figures in brackets). The United Kingdom was the main market for these exports. Chrome and manganese ores are imported, some from Russia. Production of these ferro-alloys started after the first world war, a number of plants being turned over to this field from the production of calcium carbide. The industry is largely based on the use of Söderberg electrodes developed by the Norwegian firm Elektrokemisk A/S. There are at present some eight independent concerns involved in the business, one American owned and another still having a substantial British shareholding. In 1955 they are re-

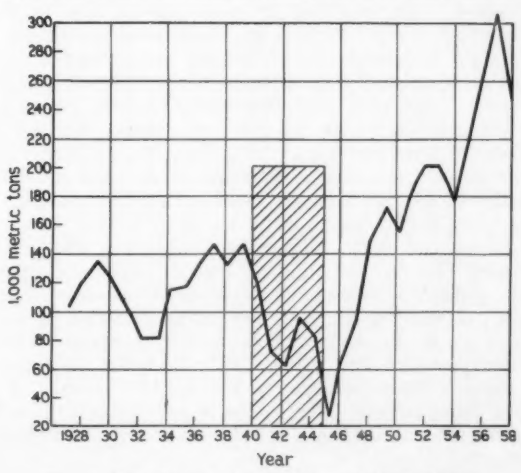


Fig. 3. Combined production of ferro-alloys

corded as having used 1,500 million kWh, valued at just over £1 million, at 0·16d. per kWh.

Aluminium

Norway's next most important electro-metallurgical product in order of aggregate export value is aluminium (Fig. 4). In 1958, a total of about 115,000 tons were produced, of which 103,000 tons were exported for £19 million to all parts of the world. Production has increased from 29,000 tons before the war; it is expected to reach 160,000 tons this year and 215,000 tons by 1961/62. The metal is mainly manufactured from alumina imported from Canada and, in future, from Jamaica. The manufacture of aluminium was first started in Norway before the first world war by S. Vigeland Brug, near Kristiansand S, owned by the British Aluminium Company. The plant has a capacity of about 3,400 tons of aluminium per annum but has now gone in for the production of super purity aluminium of 99·99% minimum purity, for which it has an annual capacity of 2,500 tons. Another early producer, Det Norske Nitridaktieselskap which began operations at Eydehagen in 1944 now has a joint capacity from two plants of about 26,000 tons per annum.

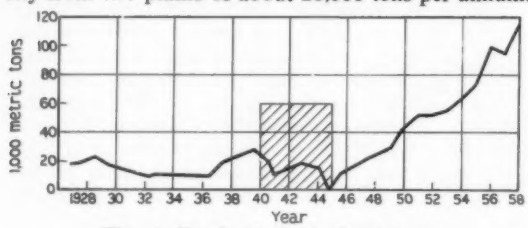


Fig. 4. Production of aluminium

This company is now jointly owned by the British Aluminium Company and Aluminium Limited of Canada. The French aluminium interests, La Societe Pechiney, also had a third share in the plant until they recently sold out to the other two shareholders. The Canadian company is also joint owner, together with a Norwegian group, de Norske Naco-Aktier A/S, of another concern, A/S Norsk Aluminium Company (founded in 1915) which owns two plants, one for processing imported bauxite into alumina and thence into aluminium at Höyanger in Western Norway with an annual capacity of 13,500 tons, and the other, A/S Nordisk Aluminiumindustri, on the Oslo Fjord (founded in 1917), for fabricating finished aluminium articles. A new plant at Mosjöen, jointly owned by Elektrokjemisk A/S, and the Swiss interests, Aluminium-Industri-Aktien-Gesellschaft (AIAG), started production last year. Its present capacity is 22,000 tons. This may be expanded to 56,000 tons later. By far the largest concern in Norway is the State-owned A/S Aardal and Sunndal Verk. This concern took over a plant in Aardal at the top of Sognfjord, begun but not completed during the last war by the Germans. This has subsequently been enlarged and is in the process of being enlarged again. The concern has also established another new plant at Sunndalsöra. The combined production of the two plants is due to reach 160,000 tons in 1962. The company has contracts to import alumina from both Aluminium Ltd., of Canada, and the Aluminium Company, of America, in exchange for fully processed aluminium ingots.

In 1955, when the whole industry's total production

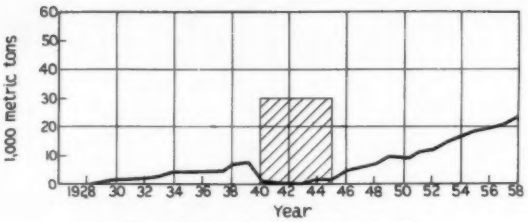


Fig. 5. Production of nickel

was just under 75,000 tons its power consumption was recorded as 1,783 million kWh at a total value of £740,000 or 0·097d. per kWh.

Nickel

The single nickel refinery in Norway located at Kristiansand is entirely owned by the Canadian Company Falcon Bridge Nickel Mines Ltd. It uses a Norwegian electrolytic process known as Hybenette. The plant was originally established in 1910, to treat local nickel ore, but nickel and copper matte is now all imported from the parent company's nickel mines in Canada. Production of nickel has risen from 8,500 tons before the war to 24,000 tons last year, and is expected to rise to 25,000 tons in 1959 (Fig. 5). In 1958, 21,000 tons were exported, to a total value of £14 million. Concurrently with the nickel production, some 11,000 tons of electrolytic copper, cobalt, sulphur dioxide and small quantities of a number of precious metals, were produced. More than half of the nickel is shipped to the United States, but some 1,500 tons were shipped to the United Kingdom in 1958. For its total refining process, the company has access to 30,000 kW capacity, at an average annual charge of just under £5 per kW.

Copper

Smaller quantities of refined copper are also produced by two other smaller concerns in Norway, A/S Sulitjelma Gruber and Roros Kobberverk, making a total production, with that of Falconbridge Nikkelverk A/S, of 17,000 tons in 1958, all of which (valued at £3 million) was exported (Fig 6).

Zinc

Zinc is produced in Norway by one firm, Det Norske Zinkkompani A/S, operating at Eiterheim, on the Hardangerfjord, an electrolytic process licensed from the Anaconda Company of America. The company was originally founded in 1923, by the Belgian firm, Cie Royale Asturienne des Mines, who still own about 45% of the shares. As a result of much investment in new equipment the plant is said to be one of the most modern in Europe. Production has fluctuated between 39,000 and 49,000 tons both before and after the war (Fig. 7). Some 37,000 tons, valued at £2·4 million, were exported in 1958. The bulk of the production is exported to Europe. Apart from zinc, the company also extracts from its imported concentrates about 100 tons a year of cadmium.

Iron and steel

A large amount of hydro-electric power is used in Norway's iron and steel industry. Possessing no indigenous coke for blast furnaces, Norwegian firms, in particular A/S Elektrokemisk, have been among the pioneers of electric smelting of pig-iron and steel.

Various methods were tried as early as 1910, but finally what is known as the Tysland-Hole process, using Söderberg electrodes and coke as a reducing agent, was successfully tried in 1922 and commercially applied at the Christiania Spigverk at Oslo in 1924. Steel furnaces began to be installed from 1927, and several other manufacturers of special steels had a combined production of nearly 70,000 tons. By 1954 this had risen to 120,000 tons. The following year electric furnaces of the new state steelworks at Mo-i-Rana, Norsk Jernverk, began operating and adding greatly to the total national production of steel. By 1958 this had risen to 360,000 tons and by the time the steelworks' present total capacity of 300,000 tons is in full operation, the national total should exceed 420,000 tons (Fig. 8). Most of the ore is mined in Norway, although some comes from Sweden. The production of 123,000 tons of pig-iron and of 171,000 tons of steel in 1955 appears to have consumed nearly 480 million kWh costing just under £350,000 or a little less than 0·18d. per kWh. In 1958 there were exports of 55,000 tons of pig-iron valued at £1·3 million, 38,000 tons of raw steel valued at £1·3 million, and 55,000 tons of tool and other steels valued at £2·5 million.

Other Electro-Metallurgical Products

Apart from the small quantities of cobalt and precious metals, produced by Falconbridge Nikkelverk A/S and of cadmium produced by the Zinc Company, mention should be made of silicon carbide, production of which was first started in 1913 by A/S Arendal Smeltverk at Eydehavn, owned by the Carborundum Co., and of rockwool, of which three companies are said to produce 20,000 tons a year. Most of the rockwool is consumed in the country, but the exports of silicon carbide are said to satisfy nearly one-third of Europe's total requirements.

Electro-Chemicals

Norwegians were also pioneers in the electrochemical industry. Two Norwegians, Professor Kristian Birkeland and Samuel Eyde, were responsible for setting up the world's first synthetic nitrogenous fertiliser factory in 1905. Their concern, known as the "Norsk Hydro-Elektrisk Kvaelstofaktieselskab" or "Norsk Hydro" for short, perfected and installed arc furnaces of their own invention. Their process has subsequently been superseded by the Haber-Bosch process, but with the help of French and German capital (the latter now taken over by the Norwegian State) the Company has expanded into far and away Norway's largest single industrial concern, with fixed capital assets of over £50 million and a turnover in 1957/58 of nearly £25 million. It operates separate major plants at Notodden, Rjukan, Eidanger, and Glomfjord (above the Arctic Circle), and owns six power stations with a maximum installed capacity of over 650 MW producing on an average 3.500 million kWh a year. Measured in terms of the nitrogen contained, the Company's production in 1957/58 rose to the record figure of 230,000 tons, from less than 100,000 tons in 1947/48 and somewhat less in the immediate pre-war years. The many different nitrogenous products based on this pure nitrogen earned an income of £18 million in the last financial year. These include nitrate of lime (well over one million tons a year), sodium nitrate, complete fertilisers (200,000 tons), ammonium nitrate limestone and urea, etc. Other important products of "Norsk Hydro" are magnesium, "heavy water" and plastic raw materials (P.V.C.). The possibility of manufacturing titanium is being investigated.

Another important group of electro-chemicals produced in Norway comprises calcium carbide (Fig. 9), cyanamide and dicyandiamide. This is actually the oldest electro-chemical industry in Norway, the German firm Siemens-Schukert having founded a calcium-carbide manufacturing unit, A/S Hafslund-Karbid Fabrikken in 1899. Other units, the Meraker Smeltverk (controlled by the Union Carbide and Notodden Calcium Carbidfabrik A/S, now closed) followed soon after. The Odda Smeltverk company, bought over in 1938 by the British Oxygen Company, was originally established in 1908. It shares with Det Norsk Nitridaktieselskap and Det Norske Zinkkompani (see under electro metallurgical products above), the very cheap hydro-electric resources of Tysseldal which drain into the southern branch of the Hardanger Fjord. (The installed capacity of the Tysefaldene Power Company is 100 MW with the possibility of developing a further 90 MW.) Already by 1910 Norway's total production of calcium carbide was 50,000 tons a year and satisfied 20% of the world's demand. This production reached a peak of over 70,000 tons in 1938. As the demand for this chemical has fluctuated rather severely the four industrial units mentioned have tended to diversify or change their lines of manufacture. A/S Hafslund Karbidfabrikken for instance, as already mentioned, have gone in for ferro-alloys while Odda Smeltverk have gone in for processing their calcium carbide further into cyanamide, a good fertiliser, and dicyandiamide, a valuable intermediate for melamine plastics. The Odda company's production in 1957/58 was 54,000 tons of raw calcium carbide. Their sales included 33,000 tons of packed carbide, 11,000 tons of cyanamide and 5,500 tons of dicyandiamide. On the other hand, for the purpose of supplying themselves with acetylene for the manufacture of P.V.C., Norsk Hydro have just established a new calcium-carbide plant with an annual capacity of 25,000 to 30,000 tons. About half of the production is at present exported.

The complete list of electro-chemicals manufactured in Norway is far too long to be detailed in this article, but brief mention must be made of the electrolytic production in Norway of hydrogen, consumed *inter alia* by the hardened-fish-fat industry; of chlorine bleaches for the pulp mills; of caustic soda used in the cellulose industry; of potassium chlorate used in the match and explosive industry; of sodium chlorate used as a basis for weed killer and bleaching; and of superphosphates, another popular fertiliser produced by the Lysaker Kemiske Fabrik A/S, founded in 1859, and by Norsk Zinkkompani. The aggregate super-

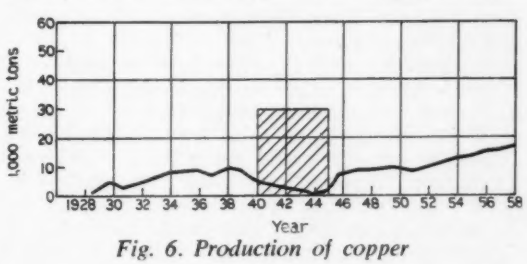


Fig. 6. Production of copper

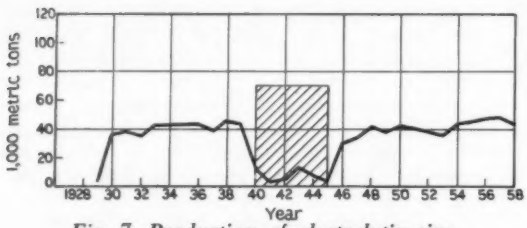


Fig. 7. Production of electrolytic zinc

phosphates productive capacity of these two firms is about 120,000 tons a year.

Future Development

The critical question for Norway is how fast her electric resources can be developed. The answer depends on a number of factors, among them, the rate of growth of domestic and industrial consumption and the ability of the country to finance, with its own or borrowed capital, a costly programme.

Official researches suggest that the demand for power will rise from an actual consumption of 27,000 million kWh in 1958 to a figure of 36,000 million kWh in 1965. The demand of the electro-chemical and metallurgical industries alone, acording to present plans (which might well be augmented later), is expected to rise from about 11,000 million kWh in 1958 to 17,000 million kWh in 1965. To meet the estimated demand by 1965, the authorities calculate that installed capacity will need to rise at an average annual rate of 400 MW. This compares with a prewar rate of increase of only 40 MW and a postwar average of about 200 MW. This has admittedly exceeded 300 MW during the last five years. The proposed rate of expansion implies an annual average capital expenditure of over £20 million a year for generating capacity alone. Together with distributional and other necessary equipment the annual rate of expenditure on power development is estimated to reach nearly £35 million in the year 1961. This is a heavy rate of expenditure for a population of only 3½ million and an estimated gross national product in 1958 of some £1,500 million. Norway admittedly has one of the highest rates of saving and investment per head in Europe but in the years to come she has heavy shipbuilding, industrial and other capital programmes to finance as well. The shipbuilding and industrial programmes alone are expected to be about £20 million a year between them.

The Government and municipalities who between them now own three-quarters of the installed capacity in Norway, have, in the past, financed their expenditure on power development to some extent out of current income but to a much larger extent out of budgetary appropriations and the proceeds of domestic and foreign loans. The present working surplus of the State and Municipal power plants is understood to be small—less than £4 million in 1955—and not all of this is automatically available for expansion. Unless therefore current power tariffs were raised not much capital can be set aside from current income. The raising of tariffs would be a difficult and unpopular measure when the cost of living is already rising rapidly. Money for power development has been, and no doubt still could be, raised locally by the Central Government and the municipalities, through taxation or loans, but the Government are loath to raise the existing power tax which was first imposed only a few years ago, and are averse to burdening further the already overstrained local money market for fear of pushing up interest rates and thereby prejudicing their "cheap money" policy. Since the war both the Central Government and the Oslo Municipality have between them borrowed for power development from the International Bank and the United States, Swedish and Swiss bankers, the equivalent of over £22 million, and the Central Government recently negotiated another loan in New York for $15 million.

Power Export

The Government undoubtedly hope that in the years to come they will be able to borrow still more money from foreign sources. Nevertheless, the cost of these loans is steadily rising. Not only are the aggregate servicing requirements of these loans mounting, but the rate of interest that has to be paid is also higher in line with the rise in interest rates throughout the world. In 1947 they were able to raise a loan in the U.S.A. for as little as 3½%. More recently they have had to pay 4¼% in the U.S.A. and the Netherlands, and 4½% in Sweden. In 1958 for a 15-year loan they had to pay over 5% in the States. They have accordingly been considering the possibility of raising loans more cheaply, or at any rate of servicing them more conveniently, by linking their borrowing to power export schemes. Under one such arrangement, concluded with Sweden in 1955, they have financed the greater part of the cost of constructing what is known as the Upper Nea Project, located between Trondheim and the Swedish border. In return for a loan, equivalent to about £4·5 million to be serviced at the rate of rather less than £430,000 a year, the Norwegians are to transmit between 200 and 400 million kWh a year at an average price per kWh of 0·31d. For this the Stockholm Municipality is expected to pay on the average over £485,000 a year. By the time the contract expires, i.e., after fifteen years, the Norwegians expect to have

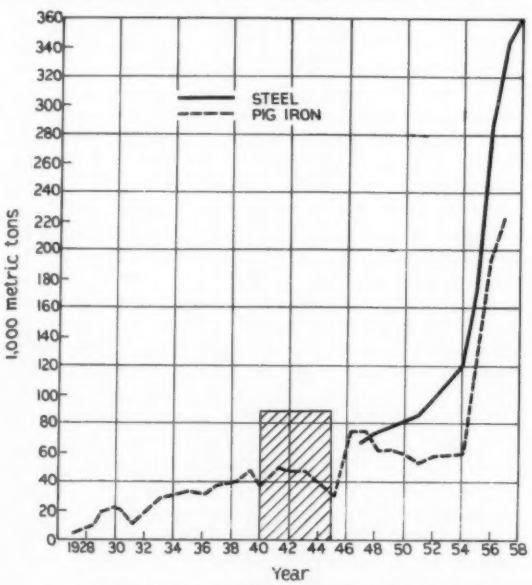


Fig. 8. Production of pig iron and raw steel

received in all a net sum of about £7·5 million, to be then able to retain the entire output of the 140 MW plant and meanwhile to draw 270 million kWh a year from the plant themselves. This would seem to have been a very satisfactory arrangement for the Norwegians, and it is little wonder that the Norwegian Government would like to make further similar arrangements. Obviously the nearest potential purchaser for her power is Sweden, but the possibility is also being investigated of exporting power to Jutland by submarine cable. The power might then be transmitted further by land to Germany. The submarine transmission of power even to Scotland has been thought of, but not seriously considered because the cost of power transmitted in this way is not expected to be appreciably lower than that of nuclear power in due course.

Various international bodies have recommended that Norway should ease Europe's power shortage in return for capital assistance to develop her resources. It has even been suggested that she could obtain a better return on her capital investment, but admittedly employ much less labour, if she exported her power rather than applied it to the manufacture, for instance, of aluminium. In general, however, the national instinct remains opposed to the idea of power export. Those Norwegians who, for various reasons and at different times, have had to submit to rationing of electricity in their homes, and those small sections of the population in outlying districts who are not yet supplied with power, or only inadequately, feel that their wants should be satisfied before there is talk of exporting power. Emotionally many sections of the population are averse to assisting the Swedes by supplying power. Norwegian industrialists feel that they are under many handicaps vis-a-vis their neighbours, and that they should retain within their control their one great asset—cheap power—rather than share it with actual or potential competitors. Their objections might be somewhat less if it was a case of selling power which owing to high transmission costs would be too expensive for manufacturing purposes, but would still be readily accepted by non-industrial consumers, such as farmers in North Denmark or householders in North Germany.

While the Government may well seek to interest neighbouring countries in the exploitation of Norway's power resources they regard power export as only a temporary and second-best solution to their problem. They are to some extent urged on to adopt it by the remote fear that nuclear power might become as cheap as hydro-electric power sooner than expected. No doubt any advances of capital in the form of foreign exchange or any plans which were calculated to provide them ultimately with the sole possession of additional generating capacity would always be attractive. But in order to provide local employment, the Government would far rather see the power consumed by manufacturing industries within the country itself. For once dams and power plants have been built, very little labour is employed in operating and maintaining them.

The establishment of electro-chemical, metallurgical or any other form of modern industrial plant, however, likewise raises the problem of capital investment. As already explained, there is a shortage of capital in the country and it is for this reason that the

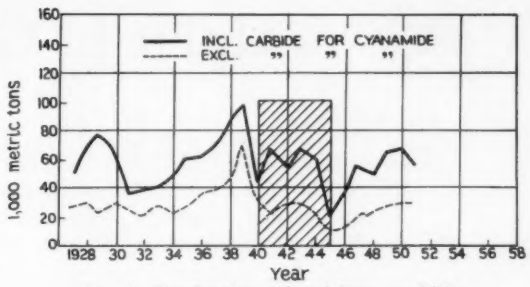


Fig. 9. Production of calcium carbide

Government have many times declared that they would welcome foreign investment in local industry. It is true that the expansion plans of existing companies, reaching into the 60s, look like absorbing much of the increased output of power proposed, but it is understood that, if necessary, and if a foreign company with suitable qualifications require it, more power could be made available beyond the programme already planned. They cite, for instance, as a project not already included within the existing programme, one near Flekkefjor between Kristiansand and Stavanger, with a potential capacity of over 1,000 MW. This, they believe, would prove to be cheaper to build than some of the more recently completed projects.

Foreign Investment in Norway

As has already been explained, foreign capital has taken a large part at all stages in the development of Norway's electro-chemical and metallurgical industries. Indeed the question might be asked, "Why, if the opportunities for profitable manufacture in Norway are so good, have existing or new foreign firms not expanded, or established new plants, more rapidly?" Why, too have certain firms, who have been established in Norway for many years and are well aware of local possibilities, chosen to invest far larger sums in Canada in the postwar period than in Norway? There have been a number of impediments to foreign investment in Norway in the past and some of them admittedly still survive. Many of Norway's concession laws governing the development of waterfalls, passed in the first flush of independence, severely restrict the operations of foreign companies in principle. Fortunately, they contain escape clauses which empower the Government to make exceptions if these are considered to be in the national interest. The Government has made, and still makes, free use of these clauses. Price and export controls, largely designed to subsidise indirectly Norwegian agriculture and to hold down the cost of living have at times created some friction between the Government and existing companies. Taxation, which Norwegians themselves admit to be heavy, and dividend limitation may also have discouraged some foreign firms from establishing themselves in the country. Many firms, both Norwegian and foreign, moreover, whose power concessions were obtained at the beginning of the century and have not so many years to run, are waiting to see whether or not the Government will decide to renew them and if so on what terms, before putting further expansion plans into effect. On the other hand, it should be noted that since the war one Canadian firm has chosen to increase its investment and expand

(Continued on page 37)

Uplift in Gravity Dams

In this series the author reviews the various conceptions of the phenomenon of uplift and presents his own analysis supported by experimental evidence. In the present article various devices that have been employed to determine the uplift coefficient are reviewed, and the author's apparatus and experiments are described

By SERGE LELIAVSKY, Ph.D., M.I.C.E., M.Am.Soc.C.E.

PART FOUR

THE earliest experiment belonging to this group of tests was that of the famous German scientist, Dr. Foppl of Munich (1900). The experimental apparatus is shown in Fig. 35. The experiment was a failure; in fact, the pressures (in atmospheres) at which apparently identical specimens broke, were: 11·0, 3·8, 12·0, 6·4, 15·0, 26·0, 7·0, 3·0 and 2·0 Such a wide range of variation robbed the test of all significance. The lack of consistency in the results is generally attributed to insufficiently accurate fittings and details of the experimental arrangement.

The next attempt to solve the same problem dates back to 1912. These were the experiments of Rudeloff and Panzerbieter represented in Fig. 36. As seen from this drawing, concrete specimens were subjected simultaneously to the effect of filtering water and to a direct force, which, in principle, is the correct way for obtaining the required coefficient. The results, however, were entirely inconclusive, for many reasons such as the following: (a) The specimens were held in plain metallic cups, so that the interstitial pressure was concentrated on solid, impermeable surfaces, and not on concrete; (b) the direct force was tension alone, the range of tests being, therefore, too narrow as compared with the probable error; and so on.

Attention will next be called to Fig. 37, which shows the experiments of Prof. Terzaghi. It will be observed that in this case the specimen is completely surrounded with water under high pressure (up to 400 kg. per sq. cm.) and failure takes place under the effect of a mechanical load. We have already explained that uplift force exists only when there is a difference of interstitial pressures, because so long as such pressure remains constant it belongs to the group of "neutral" pressures which have no direct effect on the mechanical behaviour of the porous material. It follows that in the experiment shown in Fig. 37, we have, strictly speaking, no uplift force at all, and the conclusions must therefore be obtained indirectly by using certain assumptions. Thus we assume that the criterion of micro-failure conforms with Mohr's diagram (Fig 38*a*); and then, comparing our results with other tests in which similar specimens were provided with metal jackets, we obtain by deduction the value of the coefficient f_s.

These experiments were widely discussed in the technical press, as regards both their argument and the numerical results they yielded ($f_s = 0{\cdot}97$ to $0{\cdot}998$). Other tests based on the same principle were carried out more recently in the U.S.A. by Douglas McHenry (1948). According to this last author, who carried out as many as 337 such tests, the fundamental equations of this solution "are based on an idealised type of failure, which is seldom encountered." Apart from that, it will be observed that according to latest views, Prandtl's diagram of failure, as shown in Fig. 38*b*, is more likely to yield the correct critical conditions when failure occurs than Mohr's diagram. Notwithstanding all this, Terzaghi's experiments played an important part in the history of the problem, and are of considerable value as extending to the case of compression the conclusions derived by Fillunger for tension alone.

In Figs. 39 and 40 we have respectively the apparatus used in the tests of R. E. Davis in America, in 1950, and in the experiments of J. Laginha Serafim in Portugal, in 1954. These comparatively recent tests deserve attention, because in both cases the specimens projected beyond the vessels containing water under high pressure; which meant that the interstitial pressures in the pores of the concrete varied from a maximum in the vessel to zero in the part beyond it. Thus the conditions required for creating an uplift force were satisfied, and, since there was also a mechanical force, the tests might have been successful had they been continued till fracture occurred. It will be observed, however, that neither apparatus provides for causing failure of the specimen, and the only manner in which its behaviour can be observed is by measuring its elongation. But as the effective area of the pores controlling the extension of a concrete specimen under seepage forces is an average for its full length, such tests could not be used to find the local maximum area causing fracture. These experiments were, therefore, unable to yield the reply to the main uplift problem required for design purposes. They were, nevertheless, interesting in throwing additional light on secondary aspects of the investigated phenomenon.

Turning, now, to the author's own experiments, which were described earlier as the "third" or "direct" solution, attention will first be called to Fig. 41, showing their main principle. In the left-hand figure we have the simplest possible device for producing failure of concrete by interstitial pressure; in fact, water is injected into a specimen projecting beyond the container, and the pressure therein is raised until the test piece bursts.

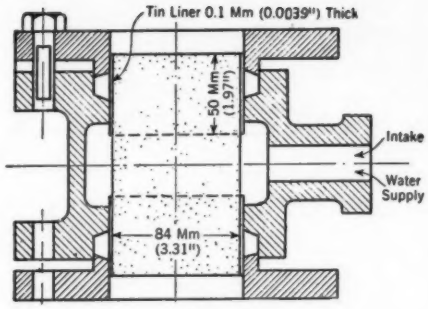


Fig. 35

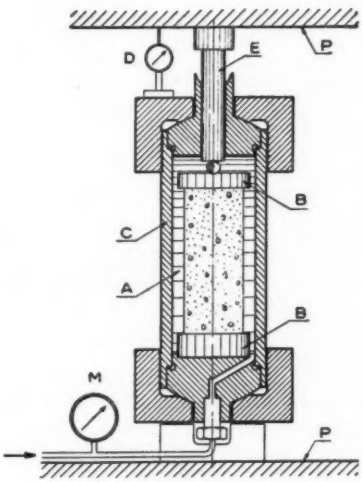


Fig. 37

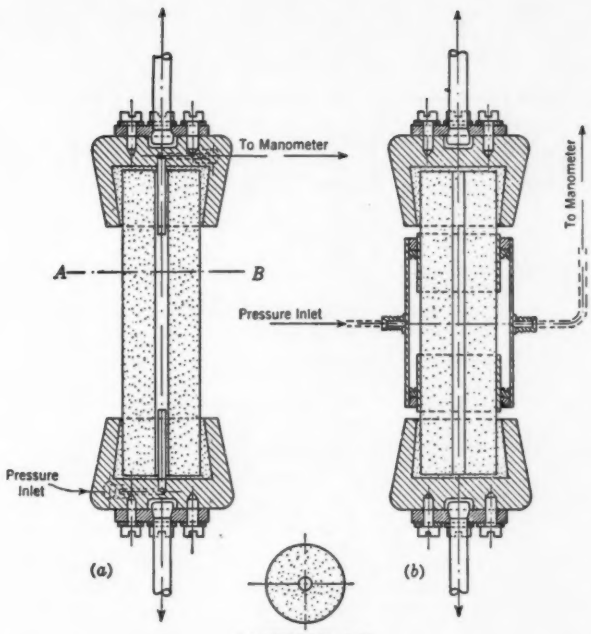


Fig. 36

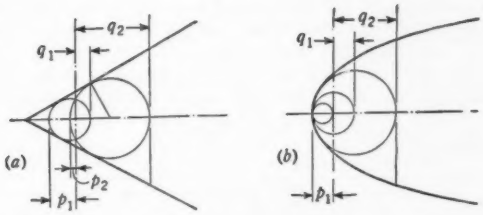


Fig. 38

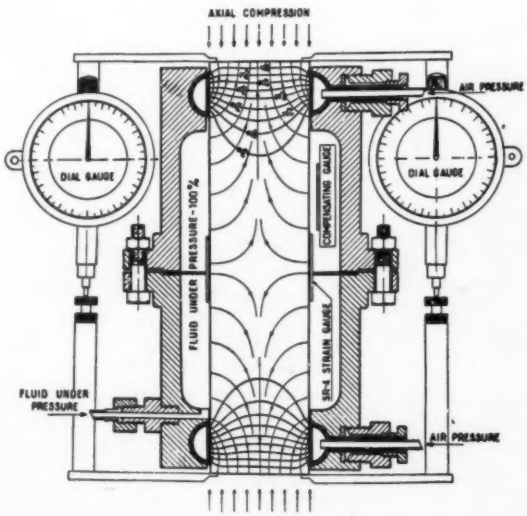


Fig. 40

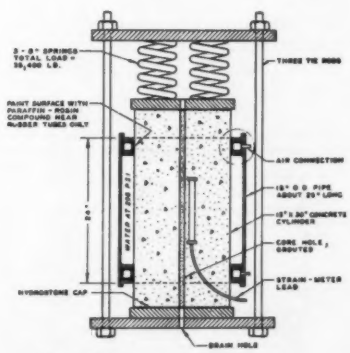


Fig. 39

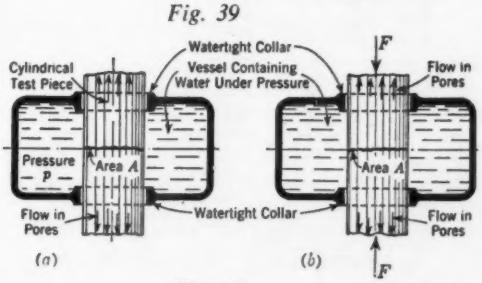


Fig. 41

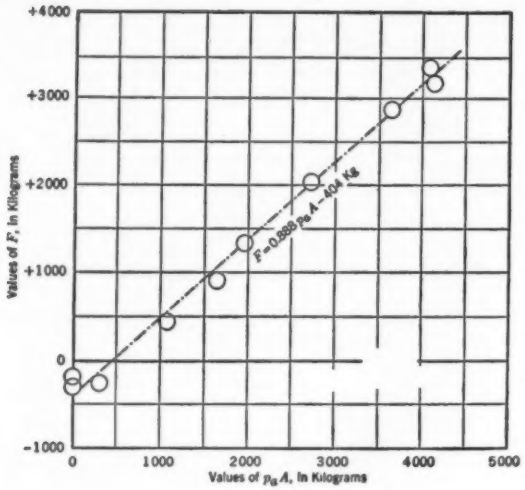


Fig. 42

This is utterly simple, but unfortunately the uplift problem cannot be solved in this simple manner, because the relevant equation $pf_sA = z$ contains two unknowns, f_s and z, which represent respectively the unknown factor of uplift and the ultimate tensile resistance of the test piece. To make the experiment significant we need a second equation, and this can be obtained by testing another identical specimen (Fig. 41*b*) in which we apply a mechanically developed force F, so that at the moment of failure we shall have

$$p_1 f_s A = z + F$$

from which

$$f_s = \frac{F}{A\,(p_1 - p)}$$

This is the principle of the solution, but in practice, since in spite of all care the values of z are never exactly equal, the experiment is repeated several times, with various values of z, and in this manner we can compute a number of equations

$$f_s p_1 A = z + F_1;\ f_s p_2 A = z + F_2;\ \text{etc.}$$

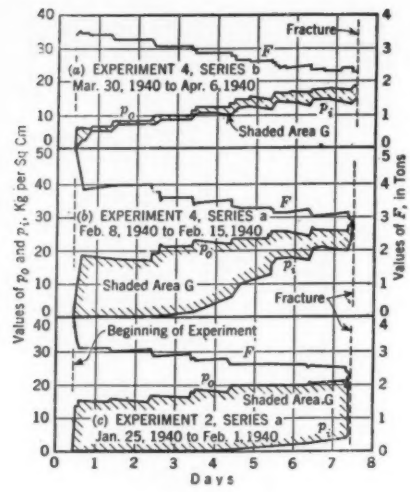


Fig. 44

Plotting the values $x_1 = p_1A;\ x_2 = p_2A;$ etc., as abscissa, against the values of $F_1 = y_1;\ F_2 = y_2;$ etc., as ordinates, we obtain a diagram such as Fig. 42. The slope of the average curve

$$\frac{dF}{dpA} = f_s$$

then gives the required value of the uplift coefficient f_s. For greater accuracy the parameters of the curve are calculated from the least-squares principle,

$$f_s = \frac{n\,\Sigma(xy) - \Sigma x \Sigma y}{n\,\Sigma x^2 - (\Sigma x)^2}$$

and

$$z = \frac{\Sigma x^2 \Sigma y - \Sigma(xy)\Sigma x}{n\,\Sigma x^2 - (\Sigma x)^2}$$

in which n is the number of tests.

The general arrangement of the specimen is shown in Fig. 43. It consists of (a) an inner core made of the

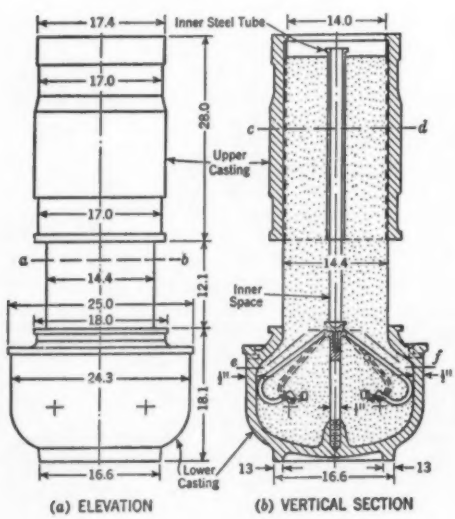


Fig. 43

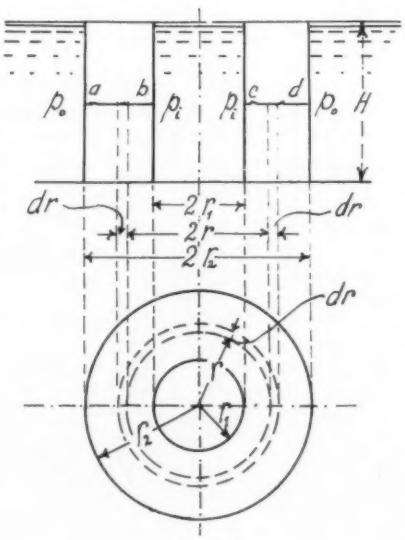


Fig. 45

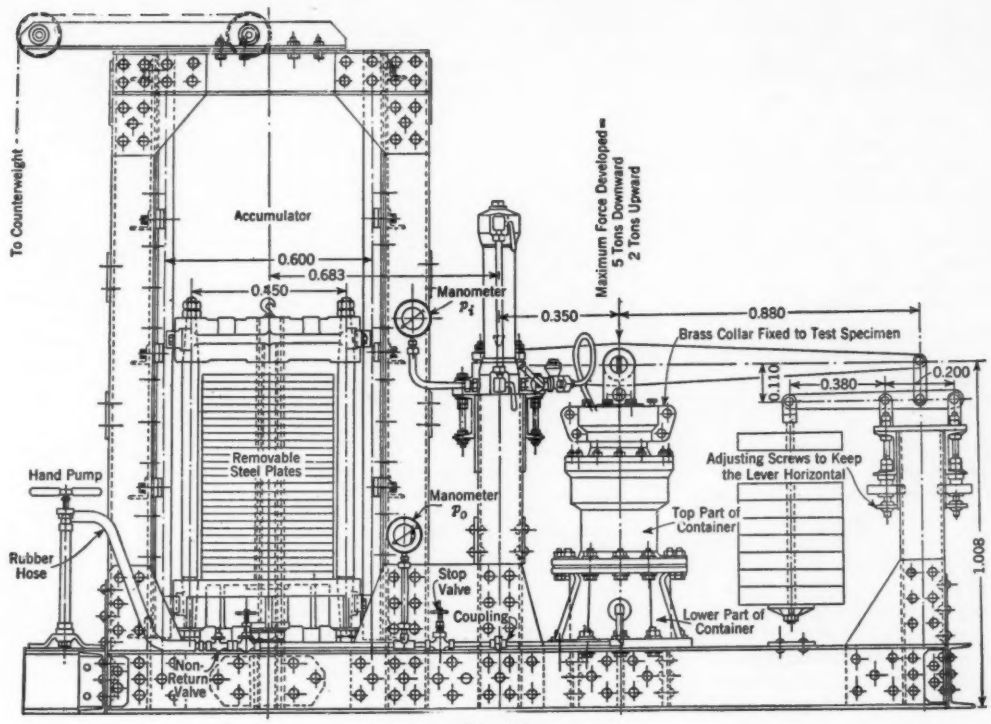

To Counterweight
Accumulator
0.600
0.683
0.450
Manometer p_i
0.350
Maximum Force Developed = 5 Tons Downward 2 Tons Upward
0.880
Brass Collar Fixed to Test Specimen
0.110
0.380
0.200
Adjusting Screws to Keep the Lever Horizontal
Removable Steel Plates
Hand Pump
Manometer p_o
Top Part of Container
Rubber Hose
Stop Valve
Coupling
Lower Part of Container
1.008
Non-Return Valve

Fig. 46

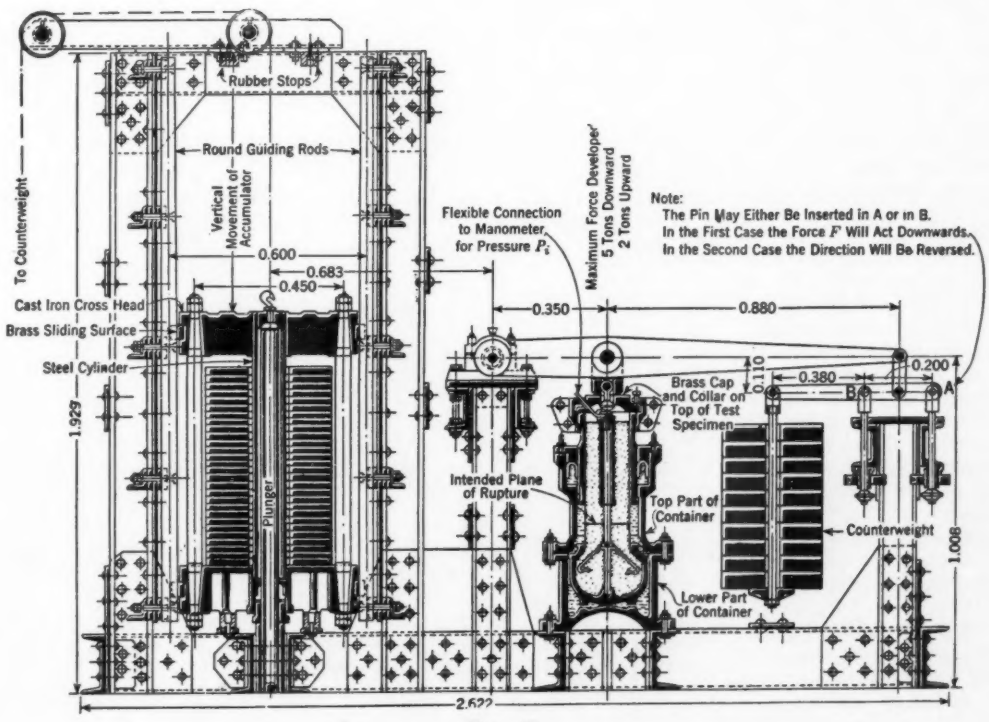

Rubber Stops
Round Guiding Rods
To Counterweight
Vertical Movement of Accumulator
Flexible Connection to Manometer for Pressure P_i
Maximum Force Developed 5 Tons Downward 2 Tons Upward
Note:
The Pin May Either Be Inserted in A or in B.
In the First Case the Force F Will Act Downwards.
In the Second Case the Direction Will Be Reversed.
0.600
0.683
0.450
Cast Iron Cross Head
Brass Sliding Surface
Steel Cylinder
0.350
0.880
0.110
0.380
0.200
Brass Cap and Collar on Top of Test Specimen
1.929
Intended Plane of Rupture
Top Part of Container
Counterweight
Plunger
Lower Part of Container
1.008
2.622

Fig. 47

material tested, (b) a cast-iron upper lining, (c) a lower casting, (d) a steel pipe in the upper part of the inner space, and (e) reinforcing bars in the lower part of the specimen, ensuring that failure takes place in the critical portion and not elsewhere.

The first point calling for comment is the asymmetrical layout of the design. In earlier tests, such as Föppl's tests shown in Fig. 35 and Rudeloff's tests shown in Fig. 36, the specimens projected on both sides beyond the container, and this arrangement was also adopted in the schematical representation of the author's experiments in Fig. 41. In detailing the apparatus it was found, however, that exactly the same results would be obtained with one end only projecting beyond the vessel, because action is always equal to reaction. This arrangement was, therefore, adopted as the much simpler alternative, the other end of the test piece being firmly fixed in the container.

The next point to decide upon was the diameter of the core. In the earlier tests these diameters were as follows:—

Föppl	... ...	8·4 cm.
Rudeloff	... ...	9·0 cm.
Terzaghi	... ...	8·0 cm.
Woodard	... ...	5·0 cm.

It must be realised, however, that the materials tested in these experiments, though described as "concrete," were actually mortar, without the addition of the coarser aggregate. Since the scope of the author's tests comprised all types of materials, it was essential to make the size of the specimen of a larger order of magnitude than that of the particles of the aggregate. The core diameter was therefore chosen as large as 15 cm.

One of the difficulties encountered by the earlier experimenters was to make sure that when failure occurred the pressure had already penetrated into all the pores of the specimen and was spread uniformly over the entire surface of rupture. Or, alternatively, if the specimen broke earlier, means had to be provided to ascertain the true average pressure as it had been

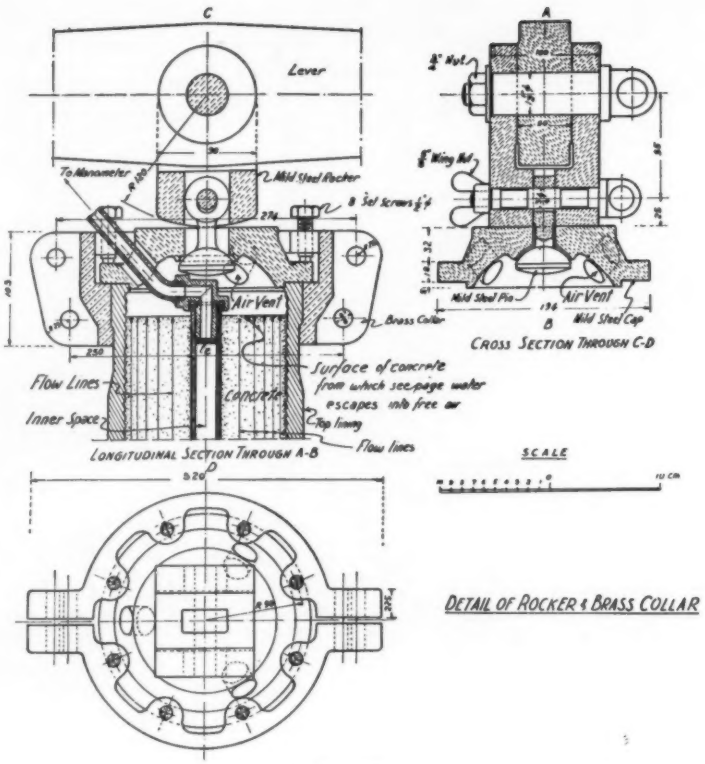


Fig. 48

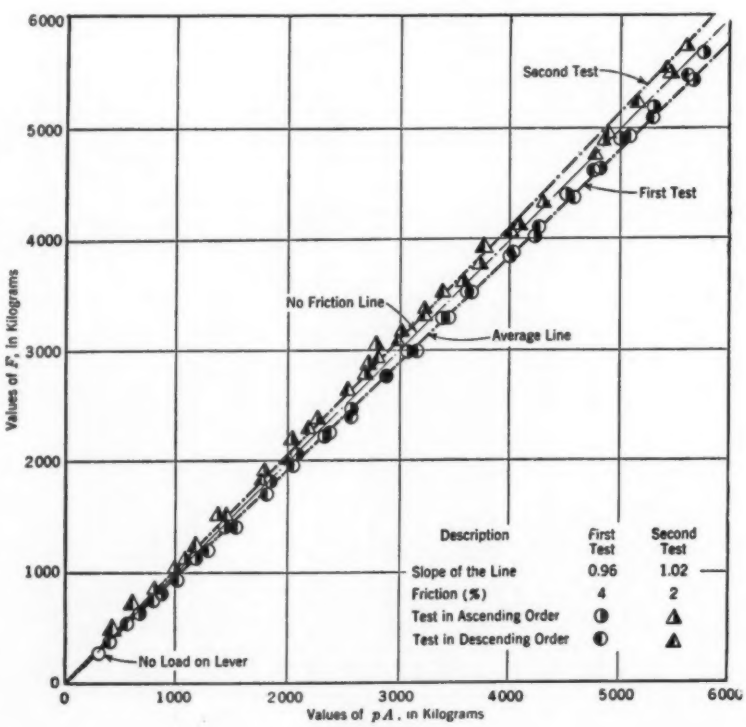


Fig. 49

Comparative Table

Showing Results of Experiments with Twelve Series of Specimens

Series	a	b	c	d	e	f	g	h	i	j	k	l	Weighted Mean
Number of tests	5	5	5	6	9	7	8	7	9	8	10	16	9·0
Dates of casting	2 XII 39	17 I 40	4 III 40	14 IV 40 and 15 IV 40	10 VII 40 and 7 VIII 40	13 X 40	16 X 40	2 III 41	15 VII 41	19 VII 41	2 II 42 and 3 II 42	8 VIII 42 and 10 VIII 42	—
Method of preparation	Concrete	Masonry	Concrete	Masonry	Concrete	Concrete	Mortar	Concrete	Concrete cast in 2 days	Concrete	Dressed Masonry work	Concrete	—
Cement, in kg. per cu. m.	530	290	500	280	300	470	435	390	325	325	330	300	359
Water-cement ratio (by weight)	0·40	0·93	0·50	0·72	0·58	0·40	0·44	0·40	0·50	0·40	0·68	0·43	0·52
Type of coarse aggregate	Granite	Granite	Granite	Granite	Granite	Gravel	—	Fine Gravel	Granite	Granite	Granite	Granite	—
Dates of testing	17 I 40 to 28 II 40	9 III 40 to 9 IV 40	22 V 40 to 1 VII 40	9 VII 40 to 23 IX 40	28 IX 40 to 4 XI 40	17 XII 40 to 20 I 41	26 I 41 to 18 II 41	15 IX 41 to 12 XI 41	14 XII 41 to 28 I 42	12 IV 42 to 30 VI 42	15 VII 42 to 25 VIII 42	28 IX 42 to 13 II 43	—
Average age, in days, when tested	70	68	101	137	68	82	115	218	151	299	179	126	130
Uplift coefficient (effective porosity) f_e	0·885	0·916	0·954	0·991	0·871	0·957	0·853	0·967	1·005	0·900	0·888	0·858	0·913
Probable error of uplift coefficient	0·098	0·030	0·093	0·040	0·038	0·062	0·033	0·080	0·034	0·054	0·016	0·017	0·043
Breaking resistance, in tons	0·795	0·138	0·458	0·474	0·845	0·929	0·326	0·978	0·791	0·947	0·404	1·058	0·727
Average breaking stress, in kg./cm.²	5·24	0·88	2·91	2·98	5·37	5·78	2·14	6·26	5·01	6·02	2·58	6·64	4·61
Probable deviation of a point, in tons	0·215	0·069	0·204	0·115	0·173	0·278	0·132	0·344	0·136	0·299	0·078	0·111	0·171
Range of F, in tons	2·597	2·673	2·630	3·611	4·174	4·232	3·477	4·030	4·056	4·049	3·500	4·284	3·756
Ratio of probable deviation to range	0·083	0·026	0·078	0·032	0·041	0·066	0·038	0·085	0·034	0·074	0·022	0·026	0·046

Fig. 50

at the moment failure actually took place. In some other tests, e.g., McHenry's and Serafim's experiments, gas was substituted for water because it spreads much more rapidly. This, however, was not fully successful, in addition to which, it appears from Serafim's tests that the effective area for gas is some 20% larger than for water.

The solution adopted by the writer was to use hollow specimens (as seen from Fig. 43). The water pressure in the container is raised in steps, the inner pressure in the specimen being allowed to rise naturally after each successive step depending on the amount of water percolating through the walls of the specimen. This procedure is illustrated in Fig. 44, in which we have three experiments with different permeabilities: very large in the upper diagram, average in the second experiment and very low in the last. It should be noted, however, that in all these three cases, as well as in all other tests performed by the author, the results were fully consistent, provided that the average pressure was calculated by the laws of hydrodynamics.

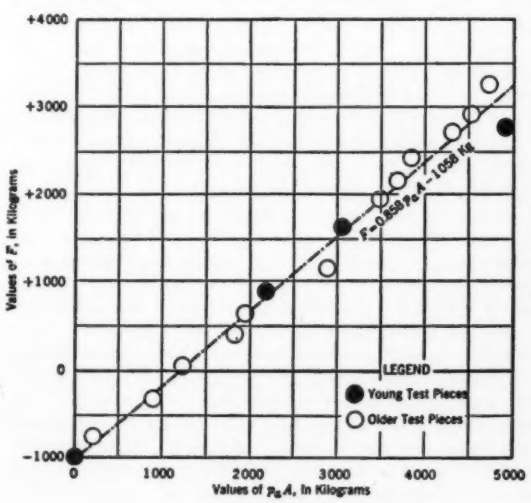


Fig. 51

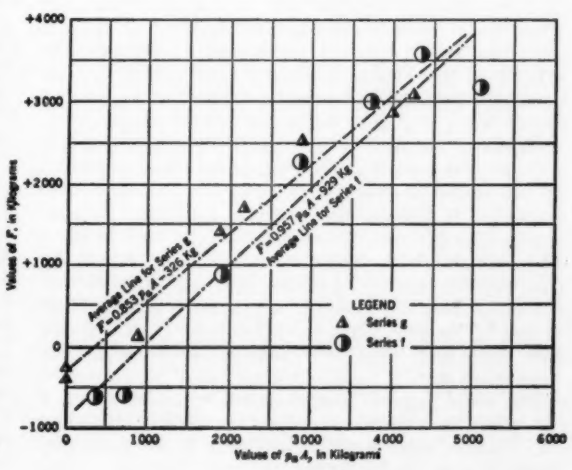


Fig. 52

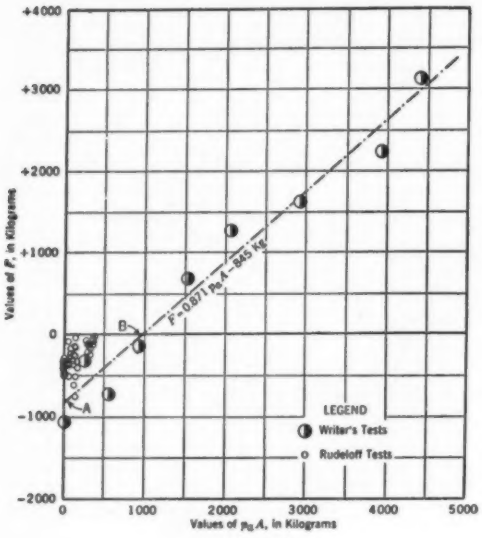


Fig. 53

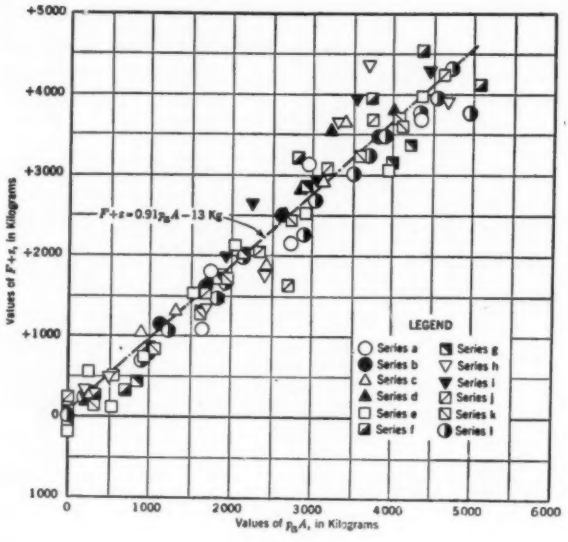


Fig. 54

Thus, referring to Fig. 45, the pressure for radius r is

$$p = \frac{Q}{2\pi Hk} \log_e r + c$$

in which Q is the discharge, k is d'Arcy's coefficient and H the height of the effective portion of the specimen. This is the standard formula. It may be transcribed

$$p = (p_o - p_i) \frac{\log_e(r/r_1)}{\log_e(r_2 - r_1)} + p_i$$

in which p_o is the pressure in the container and p_i is the pressure in the hollow space in the specimen. (To measure the latter, the specimen was connected during the test with a special manometer.) Integrating this equation and dividing by the area, we obtain the average pressure

$$p_a = p_i + (p_o - p_i)\triangle$$

where $$\triangle = \frac{r_1^2}{r_2^2 + r_1^2} - \frac{1}{2\log_e(r_2/r_1)}$$

In conducting the tests p_a was substituted for p in all cases when, at the moment of failure, p_i was not equal to p_o. The statistical analysis of the results, based on the theory of probability, confirmed the validity of this equation, since it was proved that no correlation existed between the differences $p_o - p_i$ and the departures of the results from the average curve.

In Figs. 46 and 47 we have the elevation and section of the testing machine. It consists essentially of the following parts: (a) container in which the specimen is placed for testing; (*b*) lever system, required to develop the compressive (or tensile) force F; (c) accumulator with inverted plunger, frame for carrying the loads, counterweight and manometer for measuring p_o; and (d) air vessel connected by means of flexible pipes with the inner space of the specimen and provided with a manometer for measuring p_i.

The lever system comprises the main lever and a secondary lever carrying the counterweight. Depending on whether the pin is placed in A or in B, the maximum forces may either be 5 tons in compression or 2 tons in tension. Thus, the total range is 7 tons. Special care was devoted to the design used for transmitting this force to the specimen, because it was essential to leave the surface of the concrete free, so as not to fall in the same error as Rudeloff. With this object in view, the force F is transmitted to the upper lining (see Fig. 48) and then retransmitted to the concrete core of the specimen. The top surface of the latter is thus left free so that the percolating water can freely emerge in open air.

The pressure p_a in the container is controlled by the number of removable plates on the accumulator, each plate corresponding to 1 kg. per sq. cm., to which, of course, must be added the weight of the movable cylinder and frame. On the other hand, for very low pressures (less than that due to cylinder and frame alone), a special counterweight is provided.

To ascertain the effect of friction and deduct it from the results, a special test has been carried out several times during the continuance of the experiments with a specimen which had been previously filed across. The results of one of these tests are shown in Fig. 49. Applying the least-squares principle, the friction was found to be 4%, which was taken into account in computing the results of each experiment.

Twelve series of test-pieces were tested. The results are shown in the Table, Fig. 50. The materials tested comprised mortar, concrete with various types of aggregates, and even masonry.

In Fig. 42 we have already given an example of a diagram representing the results of one series of tests, namely series k the specimens of which represented dressed masonry. Another example is reproduced, Fig. 51. The particular object in this case was to ascertain whether the age of the specimens had any effect on the results. From a series of 16 test-pieces belonging to this group, four were tested six to ten weeks after casting, while the remaining twelve were three to five months older. The younger and older specimens are shown in the diagram by black and white circles, respectively. No difference whatever can be detected in the diagram.

Another example is given in Fig. 52. In this case,

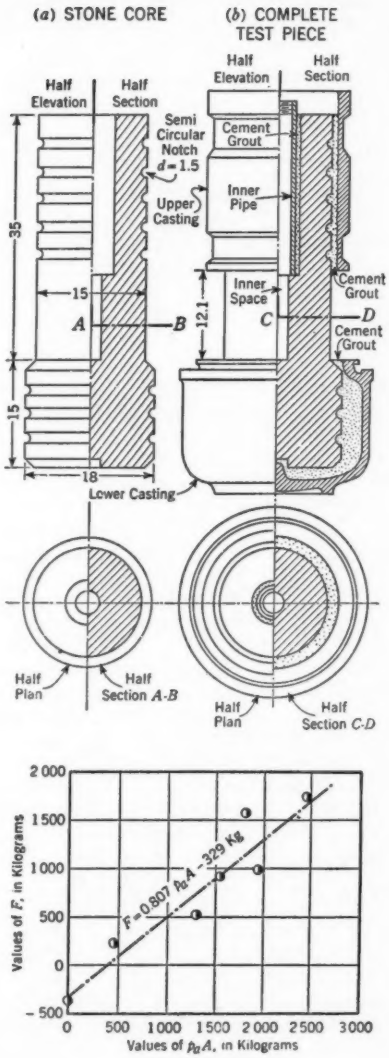


Fig. 55

two groups were shown in the same chart, the object being to compare specimens made in precisely the same manner except for the presence in one mixture (series f) and the complete absence in the other (series g) of the larger aggregate. As seen from the drawing the uplift coefficient is slightly higher in the first case, but the difference is too small to draw conclusions.

Another chart, Fig. 53, is used to show the reason for the failure of the earlier tests of Rudeloff. It will be remembered that in this set of experiments (see Fig. 36) the specimens were subject to tension forces only, and the range of conditions was therefore rather small. The points calculated from the published information on these tests (see small circles in the drawing) are therefore found to be grouped in one single "cloud", which cannot be defined as a straight line or a curve.

The striking point of the results obtained by the author with twelve groups of tests was that the differences between the individual series were surprisingly small, in spite of every effort being taken to differentiate the methods and materials. The possibility was therefore explored that the entire body of these tests might be a single, composite group. This approach would have appeared unorthodox had it been advanced at the earlier stage of the investigation, but it suggested itself later as a natural conclusion derived from the obtained numerical results. It should be realised, however, that the values of the ultimate resistances z, characteristic of the different series, were not, and could not have been, the same. Hence, they were removed prior to combining the tests in a single diagram, values of $F+z$ being plotted as ordinates against $p_a A$ as abscissae. The results are shown in Fig. 54.

The correlation method was adopted for the statistical analysis of this diagram. The results were as follows:—

	Correlation	*Regression*
Coefficient	$r=0{\cdot}974$	$b=0{\cdot}91$
Probable error	$\Delta r=0{\cdot}0035$	$\Delta b=0{\cdot}014$
Approx. ratio	$\Delta r/r=1:300$	$\Delta b/b=1:70$

It will be realised that these figures are extremely satisfactory. The curve in Fig. 54 is therefore accepted as final and the relevant value of the coefficient of uplift recommended for all cases is $f_s = 0{\cdot}91$, the corresponding probable error being only 1·5%. The value of the coefficient f_v determined earlier being 0·07, the coefficient for design purposes becomes $0{\cdot}91-0{\cdot}07 = 0{\cdot}84$, or in round figures,

$$f = f_s — f_v = 0{\cdot}85$$

After these results were published some American authors suggested that, being derived from tests with concrete and masonry, it was possible that they did not apply to rock foundations. An additional series of tests was therefore carried out by the author with sandstone test-pieces as shown in Fig. 55. The results, reproduced in the same drawing, were similar to all other tests made with concrete and masonry.

The author's tests received much attention in the pages of various technical books and periodicals. It might therefore be not out of place to mention here one of the latest opinions on the subject, due to an American authority, Mr. Roy W. Carlson: "The only known and defensible method for determining the one maximum pore area which exists in a specific concrete is that of testing to failure, as was done by Leliavsky. . . ." He says further: ". . . the writer (i.e., Mr. Carlson) agrees with Mr. Leliavsky that the 'weakest section' is the one which should govern."

It remains to add a few words about the physical explanation of so high a percentage of pore area, obtained in the experiments. What is particularly surprising is the constancy of this factor, which remains the same for all types of materials and methods. In addition to Prof. Terzaghi's concept of a surface of maximum porosity, as represented earlier in Fig. 10*B*, Prof. Raes has pointed out that f_s must also depend on the slope of the surfaces of micro-failure, so that with a constant slope one might expect a constant uplift factor. To explain the point, consider Fig. 56, which represents, to a largely magnified scale, two cases of micro-failures in a porous solid. It is not intended to demonstrate that the shape of the pores is exactly such as is shown in this drawing, but whatever that shape may be it is obvious from the diagram that the thick vertical lines, representing shear failure, yield a much

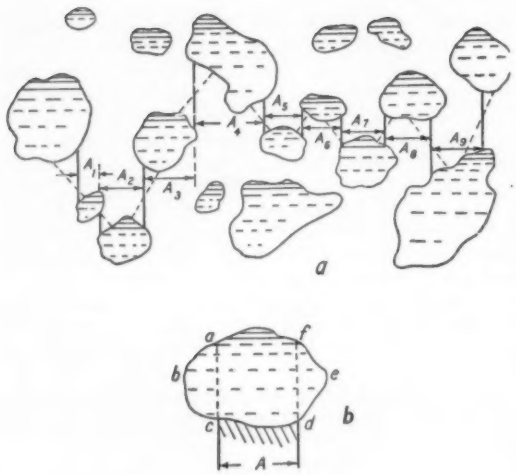


Fig. 56

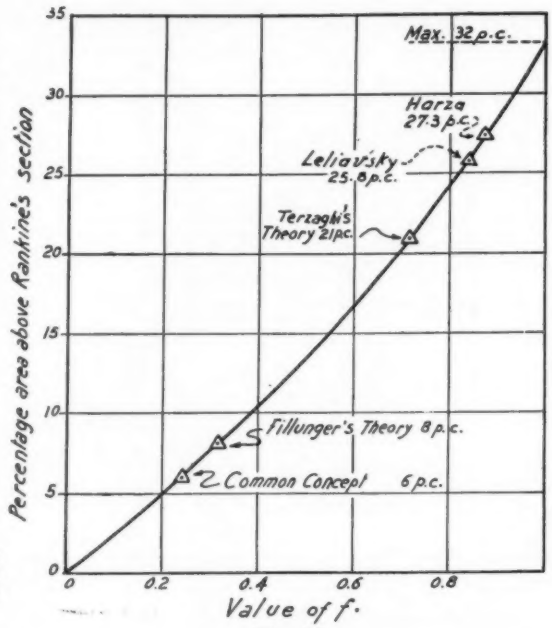


Fig. 57

larger porosity factor than the inclined dotted lines, which correspond to the case of shear-cum-tension failure. In the first case we get about 100% compared with 70% only in the second.

In the first article a diagram was given showing the economic aspect of the various theories of the older group based on the concept of an imaginary crack. In Fig. 57 we have another similar diagram showing the percentages of extra material required to satisfy the theories of the second group, which contemplate seepage as a natural physical phenomenon. Here again, Rankine's middle-third profile is taken as basis, and the various methods, here described, are represented in relation to the extra material they require. As will be seen from the chart, the assumption of a 100% uplift area calls for 32% extra material, just in the same way as Maurice Levy's principle in the old theories. Several other points are also shown in the drawing, referring respectively to Fillunger's, Terzaghi's and various other solutions. The extra material corresponding to the author's solution is 25·8%.

(*To be continued*)

Twenty-one years of Short-Circuit Testing of Switchgear

The Association of Short-Circuit Testing Authorities, founded in Britain in 1938, celebrated its coming of age at a dinner held in London in December. Before its inception, switchgear for high-voltage systems was designed and tested on purely empirical lines, and failures in service could seldom be related to specific design or operational causes. In 1938, the seven leading manufacturers of switchgear in Britain joined together and set up a body, in association with the National Physical Laboratory and other interested organisations, to prepare a rigid test code. The four short-circuit testing stations which they owned between them were all operated on the basis of this code, and the ASTA Certificate of Rating rapidly began to assume the same importance as the Plimsoll Line has gained for itself in the shipping world.

Since its inception, ASTA has increased its membership to eleven companies, operating eight testing stations. It has made arrangements whereby the switchgear made by non-members can be tested at any of the stations, under conditions of strict confidence.

The testing stations now operated by ASTA comprise some of the largest in the world. The ASTA Certificate is internationally recognised, and is continually revised in the light of the latest research not only into arc control and switchgear design generally, but also into system operation. The methods of test evolved by ASTA have been adopted not only by the British Standards Institution, but also by the International Electrotechnical Commission.

The President of the Institution of Electrical Engineers, Sir Willis Jackson, said at the anniversary dinner that the work of ASTA was seldom appreciated by the electrical-engineering profession as a whole, and never by the general public; yet it had made possible a standard of safety and security of public electricity supply which is as high, if not higher, than that achieved anywhere else in the world. That this standard has been achieved by voluntary co-operation between manufacturers is a remarkable facet of the twenty-one years of work by this unique body.

A Useful Handbook. The 1959–60 edition of the Handbook of the Federation of Civil Engineering Contractors is now available. The Handbook lists the names and addresses of the 680 members of the Federation and contains all the main Federation documents including the Working Rule Agreement of the Civil Engineering Construction Conciliation Board, the I.C.E. Conditions of Contract and the Federation Dayworks Schedules.

Copies of the F.C.E.C. Handbook 1959–60 may be obtained, price 12s. 6d. post free, from the Federation of Civil Engineering Contractors, at Romney House, Tufton Street, Westminster, S.W.1.

The IAHR Montreal Congress

A series reporting the proceedings of the International Association for Hydraulic Research Eighth Congress held in Montreal, Canada, in August, 1959. Many of the papers reviewed are likely to be of particular interest to hydro-electric engineers and to the designers of hydraulic structures

PART THREE

SEMINAR ON ICE PROBLEMS IN HYDRAULIC STRUCTURES

ICE problems attracted such widespread attention that the Association decided to set up a permanent committee under the chairmanship of Renée Dupuis, Quebec Hydro. The informal introductory notes submitted were summarised and presented for discussion by K. G. Henry and D. M. Foulds, of Ontario Hydro.

Theory and Experiments on Ice Formation

No. 9SI. (Williams, Canada) reported laboratory experiments on water supercooling factors during frazil ice formation which indicated that this transient phenomenon depends on the cooling rate and the surface available for ice formation and that difficulties will be encountered in ascertaining its extent under field conditions.

No. 10SI. (Williams, Canada) presented an empirical method for estimating total heat losses from open water surfaces using the sol-air temperature concept which combines heat transfer by radiation or convection effects with Bowen's ratio for evaporation and convection losses. Laboratory experiments suggest that water surface/mean sol-air temperature differences can be used to predict water surface heat loss rates and frazil ice formation.

No. 5SI. (Hausser and Michel, Canada) studied temperature under river ice covers which showed that it increases as the water progresses because of heat:—

(a) Release or absorption.
(b) Release by potential energy losses and river bed.
(c) Transfer through the ice cover.

Thermal equilibrium equations for water entering under the cover, with or without ice particles in suspension, were applied to the Beauharnois Canal to ascertain the ice volume melted by the flow and again in *Note No. 6SI.* for the quantity of ice deposited below the cover or passed through the turbines.

No. 24SI. (Nybrant, Sweden) discussed reservoir water temperatures and flow in mathematical terms and in relation to the volume circulating from the deeper parts, water surface heat losses and bottom heat supply. Water temperatures were measured to observe the effect of reservoir inflow and discharge. It appears that after a pond has frozen over the temperature rises about 2°C. and subsequently continues to fall, because of different current conditions in an ice-free and ice-coated pond. Under the latter conditions ice friction reduces the water velocity of the uppermost layers, whereas those deeper down accelerate to convey a greater proportion through the pond and consequently the out-flow temperature rises.

No. 8SI. (Hausser and Beauchemin, Canada) described experimental work on the open surface ice production rate relative to MacLachlan's empirical formulae based on ice jam and cover volume measurements. Computations involving water convection cooling, evaporation, wind and radiation differed possibly because MacLachlan's formulae neglect reduced water cooling by frazil ice and cold weather fog formation. The statistical correlation of day and night ice formation with temperature and wind speed seem to verify these contentions.

No. 12SI. (Cartier and Beccat, Canada) outlined full-scale experiments on the ice cover formation mechanism for analysis of buoyancy, submersion of superficial floes and maximum velocities against which ice covers build up or recede. Theory relates this accumulation process to a definite thickness of drifting floes carried below the cover as it builds up following transportation laws analagous to those for coarse materials on stream beds. A cover may grow and consolidate when its upstream thickness prevents submersion and co-ordinates:—

(i) Minimum stable ice cover thickness with mean flow velocity.
(ii) Upstream advance with the incoming flow conveyance and maximum transportation rates.

Analysis of the experimental data confirms that the critical velocity depends on canal depth and that the conditions for ice cover formation and advance are related to flow velocity and the incoming ice.

Formation, Movement and Agglomeration of Ice in Lakes, Rivers and Canals

No. 4SI. (Pariset and Hausser, Canada) dealt with the "Evolution of Ice Covers During their Formation" and defined:—

(i) *Normal Ice Covers*: Where the velocity is subcritical. With adequate ice discharge, the cover progresses upstream with a definite thickness at a rate depending on the amount of ice supplied.
(ii) *Hanging Dams*: Where the cover has abnormal thickness in shallow water at relatively high velocity.
(iii) *Ice Jams*: Where the cover reaches a section with super critical velocity the ice floes pass under it and the progression ceases, but the thickness increases progressively downstream until the velocity becomes sufficient to transport all drifting ice.
(iv) *Dune Formation*: Below the ice cover induced

by velocity or solid discharge variations. These conditions were reproduced in the laboratory.

These studies show the importance of temperature on the ice cover length and progression rate. Ice cover should form in the forebay at a water velocity of:—

(a) 1·4–1·6 ft./sec.
(b) 2·2 ft./sec. provided the temperature drops below zero for several days, otherwise a longer reach of the river remains to generate frazil ice.

No. 3SI. (Pariset and Hausser, Canada) dealt analytically with river ice cover formation and laboratory verification in terms of the progression mechanism:—

(a) By floes drifting against the ice cover. They will remain in stable equilibrium only if the thickness is adequate, otherwise they will overturn and pass under the cover.
(b) By floes piling up under the cover until the minimum thickness is sufficient and stable enough to grow upstream.
(c) Which ceases if the ice transported exceeds that feeding the cover.

Equations for these processes, applied to the Lachine Section of the St. Lawrence Seaway, showed that the critical velocity varied between 1·5 and 2·2 ft./sec. Further studies will permit more precise forecasting of ice cover progression.

No. 6SI. (Hausser and Galiana, Canada) related to "Transportation and Deposition of Frazil Ice Under Ice Covers." Since frazil ice is transported in suspension, turbulence phenomena make similitude impossible and calculations using a silting basin analogy with field check measurements are attempted to determine ice concentration and thickness deposited along the cover. The percentage of ice in suspension is related to dimensionless parameters of distance, water depth, flow velocity and upward velocity of frazil ice particles.

No. 1SI. (Kivisild, Canada). This note on "Hanging Ice Dams" maintained that once an ice sheet forms, incoming shale ice is stopped and adheres to the upstream end in thin layers or a thick mass. The Froude number seems to determine these conditions. Below $F=0{\cdot}08$ ice accumulates and packs upstream. At higher values it is washed under the ice cover and deposited at sections where the shear stress is subcritical, thus increasing the velocity to transport incoming ice further downstream. Hanging dams beneath the ice cover diminish the water area and produce critical slopes over progressively increasing distances until the water levels and hydraulic conditions become favourable for upstream ice accumulation and packing towards the next critical section.

From average ice roughness and critical shear stress, critical depths are established which have a definite relationship with critical slope and flow per unit width.

No. 25SI. (Scherman, Sweden) on "Ice Difficulties in Open Water Courses of Hydro-Electric Plants" mentioned that river and power plant regulation change water flows, levels and ice-forming conditions. By plotting surface velocity against air temperature, Scherman divides the diagram into zones where:—

1. Ice cover can form and stay.
2. Frazil ice can form without an ice coat or with an earlier one:—
   (i) Remaining.
   (ii) Disappearing.
   In these two regions daily frazil ice productions are used as parameters.
3. No ice covers can form and an earlier one disappears.

The important factors for open headraces, where ice or frazil ice troubles may occur, are initial water and air temperature and other meteorological data, canal length, depth and water velocity. To diminish difficulties:—

(i) The head pond should be large.
(ii) The canal should be short and deep with reduced upstream area and increased width at the downstream end.
(iii) The plant should operate intermittently to form an ice cover quickly in the downstream region.

No. 26SI. (De Bellmond, Sweden) referred to friction loss created by surface and anchor ice. Measurements with corrections for ice cover, channel shape and head changes during the tests showed that the friction head loss was increased by the surface ice to 1·36 times that without ice cover.

Ice Problems in Hydraulic Structures

No. 17SI. (Proskurjakov, U.S.S.R.) described investigations concerned with ice problems in hydroelectric construction in the U.S.S.R. with respect to:—

(i) Winter excavation and concreting methods.
(ii) Reservoir and stream flow water temperature.
(iii) Ice processes in reservoirs, rivers and channels.
(iv) Combating ice troubles during power plant operation.

This was mainly a summary of Soviet engineers' work leading forecasting methods for frazil ice, jamming and clogging phenomena in rivers, but contained little factual data.

No. 16SI. (Korzhavin, U.S.S.R.) on "Ice Affecting Engineering Structures on Siberian Rivers" was more informative in relation to bridge pier:—

(i) Behaviour and performance during ice runs.
(ii) Design methods for vertical and inclined cutting faces.
(iii) Ice pressure measurements under field conditions.
(iv) Mechanical properties of ice in tension, compression, bending, shearing and local bearing.

No. 22SI. (Assur, U.S.A.) was devoted to a mathematical/experimental analysis of ice pressure created by penetration of a surface temperature wave as limited by buckling strength.

No. 11SI. (Beccat and Michel, Canada) related to the thrust exerted on retaining structures by unconsolidated ice covers in terms of:—

(i) Hydrodynamic thrust on the frontal edge.
(ii) Force and thrust exerted by water friction.
(iii) Weight of the cover.

No. 7SI. (Pariset and Michel, Canada) "Ice Spillways for Run-of-river Plants." Where pondage is insufficient for a continuous ice cover, ice floes may be passed over the dam and frazil ice through the turbines. An ice spillway must:—

(i) Evacuate all floating ice immediately to prevent a bridge forming and initiating an ice jam.
(ii) Break the thickest ice sheet with dimensions exceeding those of the downstream channel entrance.
(iii) Operate with maximum discharge.

Three 1 : 40 scale models tested were:—

(a) A converging surface sluice.
(b) A vortex spillway having a favourable discharge law for variable upstream water level.
(c) A semi-circular shaft spillway.

Design (c) seemed most effective, although real ice tests were made on a larger vortex model in a canal alongside the St. Lawrence.

No. 28SI. (Nybrant, Sweden) described water temperature investigations on bubbler systems and their

action. Air bubbles escaping from a hose on the lake bottom ascend at rates which increase with size and the associated frictional force transports warm water from the bottom to the underside of the ice which may melt or grow weaker.

The hose and holes must be dimensioned and spaced for maximum circulation. It was concluded from full-scale experiments with polythene plastic hoses and 0·75 mm. holes at 10 m. centres that:—

(i) The ice-free zone was 10–20 m. wide and conditions were not appreciably affected 50 m. beyond the ice fringe.
(ii) Water circulation produced temperature compensation throughout except for the bottom layers. This was concentrated in the ice-free area above the hose, but was noticeable 50 m. from it.
(iii) The isothermal layer above the hose had approximately the same temperature as the adjacent water at the same depth which was unaffected by the bubbler.
(iv) Water temperature relative to adjacent zones was only slightly reduced despite heat transmission from the open areas to atmosphere, partly because of increased heat supply from the bottom temperature stratified water and radiation through the ice-free surfaces in the early spring.
(v) In open channels the heat increase near the bottom was slower than in more distant zones.
(vi) To reduce heat loss, the area above the hose should have a thin ice cover.

No. 13SI. (Clinch, Millman and Erickson, Canada) was devoted to "Ice Problems at McCormick Dam" and to a compressed air bubbler system comprising 2–25 mm. pipes suspended 3 m. below the surface and 3 m. from the dam.

No. of holes	8	16
Diameter	1·6 mm.	0·8 mm.
Spacing	3·0 m.	1·5 m.
Air pressure	0·71–1·11 kg./sq. cm.	

The tests were devised to ascertain the volume of warm water conveyed to the surface by a given air quantity by balancing the theoretical open water heat loss against reservoir water temperature measurements. The air/water flow ratio variations are attributed to inadequate field observations.

No. 29 (Holden, Canada). Ice conditions at the Niagara power plants were graphically illustrated by photographs and the experience summary which mentioned the submerged gathering tube intakes at Sir Adam Beck No. 2.

No. 20SI. (Hunt, U.S.A.) and *No. 21SI. (Land, Canada)* reviewed conditions on the St. Lawrence Seaway where ice problems influenced the economics of reduced river flow, channel excavation, spillway design and regulation procedures. Although Hunt conceded that much will be learned from actual operation, Land maintained that while compressed air systems prevent ice formation, channel improvements and ice breakers will still be necessary.

Ice Problems with Hydraulic Equipment

Nos. 18 and 19SI. (Hagstrom) and *No. 27SI. (Johannson).* These notes dealt with Swedish practice for protection of dam gates where water seeping through the gate seals, splashing, vapour from cooled masonry surfaces, stagnant water on skinplating or freezing to the adjoining sill and piers all constitute operating hazards, such as overloading of the winches by ice loading, which may demand heating and influence the choice of gate type.

Flat wheeled gates are faced with the difficulty of effectively heating deep grooves and wheel tracks. Sector gates, on the other hand, do not require grooves and are readily kept ice free because the piers have smooth walls with the sealing strips being the only connection between the gate and the adjacent concrete. Moreover, the arms are coupled to the gate leaf away from the piers and the bearings are easy to keep ice free.

The first consideration is the heating of embedded sealing strips on the piers and sill to prevent ice formation from seal leakage and to protect the rubber seals from wear and tear.

Sector gate sealing strips and splash protection may use electrically-heated oil, circulated by pumps through pipes welded to the back of the sealing strips but low-voltage a.c. embedded heating elements or electrically-insulated reinforcing bars are also employed and extended to the embedded concrete downstreams of the seals.

The skinplating must also be insulated on the downstream side with non-hygroscopic material, such as expanded cork or glass wool, attached to protective galvanised steel or corrugated aluminium plating. The gate structure should also be heated electrically or by circulating hot air.

Generally, the zone upstream of the gates is kept ice free by infra-red radiation heaters or by circulating water, using separate air bubblers or through 0·5 mm. air nozzles incorporated in the skinplating at 0·5–1·0 m. centres about 0·5 m. above the sill.

Heat from generator and transformer cooling water pumped through discharge pipes which can be raised and lowered in front of the spillways has also been tried.

It is also possible to blow hot air from the generators into the gate chambers and lifting devices to supplement lateral seal heating and to prevent ice formations projecting from the upper sections of the concrete obstructing the passage of the gate.

No. 2SI. (Otsubo, Japan). "Ice Problems with Gates in Northern Japan." The precautions taken comprised:—

(i) Hot air blowers feeding into the gate chambers.
(ii) Enclosed pipe heaters fixed at the upstream and downstream sides of the grooves.
(iii) Infra-red lamps to permit emergency closing of normally-open gates.
(iv) Vinyl-covered steel-wire electric heaters for butterfly, exposed byepass and drain valves.

Portable crude oil burners are used occasionally but are considered unsafe for personnel and equipment.

No. 14SI. (McCaig and Haydock, Canada) described two ice prevention systems for low-level reservoir outlets where:—

(i) The sluiceway arrangement is impracticable for electrical or hot air heating of grooves and spaces downstream of the gates. In such cases the roller paths, lintels and sills can be de-iced by circulating a light, low-viscosity heat transfer oil through ducts incorporated in the embedded parts.
(ii) A de-icing system using a furnace and circulating fans to deliver hot air into an embedded header which discharges into the gate wells and elsewhere is most suitable.

No. 15SI. (Strowger, U.S.A.) discussed ice problems in relation to the structural design of hydro-electric

works in the Niagara area. The preventatives used include:—

(i) Deep intake channels permitting ice cover formation.
(ii) A minimum water depth of 2 ft. and electrically heated slots for ice sluices.
(iii) Flashboards with soil-heating cables.
(iv) Sloping dam faces coated with petrolatum to reduce ice thrust.
(v) Thin slabs with one water face, have air side insulation to prevent saturated concrete from freezing.
(vi) Heated headgates enclosures.
(vii) Tubular space heaters for exposed air vents.
(viii) Submerged screens with mechanical rakes to minimise surface and frazil ice trouble.
(ix) Surge tanks have 2 inches of insulation and a system of pumps, water heaters and nozzles to cover the exposed water surface.
(x) Sector gate protection by:—
  (a) Electric heating to avoid side and sill seals freezing to the adjacent concrete.
  (b) Bubbler systems to keep them free from surface ice thrust.
(xi) Housed flood gates with the rollers kept warm for immediate use by air or contact heaters.

No. 23SI. (Smallridge, Canada). During commissioning at the "Corner Brook Development" an unusual ice condition occurred which caused the penstock to be severely stressed. The turbine pressure relief valve is above tailwater level and before load rejection tests, cold weather followed by a thaw necessitated penstock dewatering for ice removal. Before refilling the spiral casing, operation of the relief valve and guide apparatus was checked in the dry. When the generator circuit breaker tripped on a small test load the relief valve opened but passed no water, thus producing an instantaneous waterhammer condition. Apparently cold air from the tailrace froze the water immediately upstream of the relief valve and penstock pressure packed the ice solid, thus blocking the outlet, although the relief valve piston was free. The ice was removed by heating, and to avoid recurrence, which would be serious for heavy load rejections, the relief valves now have: —

(a) Canvas flaps over each exit to prevent ingress of cold winds.
(b) A 3 kW hot air blower in each pit.

SEMINAR ON TRANSPORT OF MATERIALS IN WATER

This seminar was divided into two sessions.

Regional Reports

Presentation and discussion of overall reviews embodying typical regional problems, research, analytical, laboratory and field studies. For uniformity the Seminar Chairman, Professor V. G. Vanoni (California Institute of Technology), had asked for the material to be classified as follows:—

Initiation of Movement.
Local Bed Scour and Erosion.
Bed Forms.
Hydraulic Roughness of Alluvial Streams.
Mechanics of Transportation of Suspended Sediment.
Unsteady Processes and Formulae for Solid Transportation Rate.
Transport by Pipes.

These regional reports were presented by: Western Europe, Professor L. J. Tison of Gand University (Belgium); Central Europe, V. M. Yevdjevich of Jugoslavia; U.S.S.R., Prof. B. V. Proskurjakov; Japan, T. Goda of Kyoto University, Tokyo; S. Tanaka; North America, P. C. Benedict of the U.S. Geological Survey, Washington.

Free Discussion

This session provided an opportunity for informal exchanges on specific research, theories, concepts and inter-related topics, which were introduced by: Bed Forms and Roughness, by N. H. Brooks of California Institute of Technology; Sediment Movement, by D. V. Joglekar of Central Board of Irrigation and Power, Poona; Stream Forms, Erosion and Deposition, by E. M. Laursen of Michigan State University; Waves and Beaches, by J. Larras of the National Hydraulic Laboratory, Chatou; Equipment for Sediment Measurement and Analyis, by F. S. Witzigman, U.S. Corps of Engineers.

Seminar Proceedings

It would be impossible to correlate adequately the information on the complex questions discussed during this Seminar without reviewing the background of work already done. The notes are therefore listed for those interested in these problems.

18SII. Brooks (U.S.A.).:
Sediment Transportation and Modern Fluid Mechanics.

11SII. Blench (Canada):
The Inductive Method of Regime Theory.

2SII. Maitre, Pramanik and Sarkar (India):
The Subsidence of Sediment Particles in Water with Reference to Viscosity and Sediment Concentration.

14SII. Dementiev (U.S.S.R.):
An Experimental Study of Fluid Currents Carrying Suspended Loads.

3SII. Bouvard (France):
Inertia Effects in Suspension Transport Tests to Determine Flow Saturation.

4SII. Lorgère (France):
The Turbidity of "The Rhône" at Beaucaire.

26SII. Kniper (U.S.A.):
Sedimentation Computations.

10SII. Jarocki (Poland):
The Relation Between Suspended and Bed Loads in Rivers.

13SII. Kumin (U.S.S.R.):
Effect of Large Scale Turbulent Mixing on Bed Load Discharge.

9SII. Brush (U.S.A.):
Bed Load Transportation in a Meandering Channel.

16SII. Vanoni (U.S.A.):
Hydraulics of Alluvial Stream Roughness.

24SII. Larras (France):
Equilibrium Profiles of Sand Beds Under the Sea.

25SII. Larras (France):
Research on the Erosion of Sand by Waves and Clapotis.

17SII. Priest (U.S.A.):
Effects of Wave Height and Period Changes on Beach Profiles.

5SII. Vincent (France):
Solid Transport on a Horizontal Bed Resulting from the Combined Action of Waves and Flow.

19SII. Witzigman (U.S.A.):
United States Inter-Agency Sedimentation Instruments.

7SII. Hausser and Michel (Canada):
Stability of the Downstream Slope of Rockfill

Dykes.

8SII. Pariset and Hausser (Canada): Rockfill Cofferdam Built by Toe Dumping.

CONCLUSIONS

The Conference demonstrated that considerable advances have been made in the field of hydraulic model testing on questions which a few years ago were considered intractable because of scale or other effects influencing similitude. It was, however, evident from several papers, notably those from Japan, Germany, U.S.A. and the U.S.S.R. that correlation with field measurements is important to fully establish laboratory tests as a design facility, particularly in such matters as air entrainment and vibration.

A notable group of papers from the Netherlands dealt with gates exposed to the sea and while these relate to basically different problems, they might well serve as the starting point for study of hydraulic forces and vibration of gate structures on any pumped storage or tidal power schemes utilising sea water.

Papers on navigation lock gates were conspicuously absent but those which referred to culvert control valves revealed that much work of technical and economic importance still remains to be done.

The sessions on density currents and transportation of materials in water reviewed many problems of direct or indirect interest to hydro-electric engineers but much scope remains for field and laboratory investigations.

The seminar on ice problems was of outstanding value for its technical interest and as an up-to-date review of the vast research work in progress, much of which has hitherto remained unpublished.

The variety of measuring techniques using electrical equipment, electronic, acoustic and optical instruments, strain gauges, high speed photography, statistical and dimensional analysis and computors, for solution of problems which can only be solved experimentally or with differential equations making restrictive assumptions, has increased greatly.

The standard of the papers and discussion was exceptionally high and the bibliographies accompanying many of them are valuable introductions to the problems which were presented.

A short general meeting confirmed the appointment of new officers for the next two years and agreed:—

(i) That IXth Congress should be held in Belgrade between August 20 and September 10, 1961. The subjects for review remain to be chosen.

(ii) To the appointment of chairman and constitution of permanent committee to deal with:—

(a) Fundamental Hydraulics, Prof. J. S. McNown (U.S.A.).

(b) Hydraulic Machinery, Prof. J. W. Daily (U.S.A.).

(c) Coastal Engineering, H. J. Schoemaker (Netherlands).

(d) Ice Problems in Hydraulic Structures, R. Dupuis (Canada).

(e) Membership, Prof. L. Escande (France).

Many of the problems which were discussed during the meetings were seen at full scale during a visit to Lambert, St. Catherine and Beauharnois Locks and Power Station on the St. Lawrence Seaway.

The free interchange of ideas not only demonstrated the value of international co-operation in hydraulic research but undoubtedly contributed much to the unqualified success of the Eighth Congress which must have been most encouraging to IAHR officials and to the Canadian Committee who were the hosts.

Representation

Many well-known hydraulic laboratories throughout the world were represented, as listed below.

Canada: Ontario Hydro-Electric Power Commission, Toronto; National Research Council; La Salle Hydraulic Laboratory, Montreal; Ecole Polytechnique de Montreal.

U.S.A.: Massachusets Institute of Technology, Cambridge; U.S. Bureau of Reclamation, Denver; U.S. Corps of Engineers, St. Paul, Minneapolis.

United Kingdom: D.S.I.R. Hydraulic Research Station, Wallingford.

Portugal: National Civil Engineering Laboratory, Lisbon.

Holland: Waterloopkundig Laboratory, Delft.

Belgium: University of Liege.

France: National Hydraulic Laboratory, Chatou; Sogreah Laboratory, Grenoble; Hydraulic Laboratory, University of Toulouse.

Austria: Institute of Technology, Vienna; Institute for Hydraulic Structures, Vienna; Technical High School, Graz.

Italy: Polytechnic Institute for Hydraulic Structures, Milan.

Western Germany: Bundesanstalt Fur Wasserbau, Karlsruhe; Theodor Rehbock Institute of Technology; Karlsruhe.

Sweden: State Power Board Laboratory, Alvakarleby; Vattenbyggsnadsbyran (VBB), Stockholm.

Jugoslavia: Institute of Hydraulic Engineering, Belgrade; University of Ljubljana.

Czechoslovakia: Institute of Hydraulic Research.

Poland: Polytechnic Hydraulic Laboratory, Gdansk.

U.S.S.R.: Kalinin Polytechnic Institute, Leningrad; Institute of Civil Engineering, Moscow; Vedeneyev Institute of Hydro-Electric Research; Tbilisi Research Institute for Hydro-Electric Development.

Israel: Institute of Technology, Haifa.

Japan: Public Works and Technical Research Institutes, Universities of Tokyo, Hokkaido and Kyoto; Central Electric Power Research Institute, Tokyo.

Australia: Snowy Mountains Authority.

From page 23

its production in Norway rather than in Canada. Other large firms, even if they have placed the major part of their investment programme in Canada in the postwar years, have also re-equipped or expanded their plants in Norway. A Swiss firm, as already mentioned, has recently invested in aluminium manufacture in North Norway and a major United States oil company has also recently negotiated with the Government a concession to establish a large oil refinery in the country on terms which permit, *inter alia*, dividends above the normal restricted level to be declared and remitted to the U.S.A. over a period of years.

Altogether it must be recognised that even if some prejudice against foreign capital still survives in certain circles in Norway there are few countries in the world where that prejudice is not a good deal stronger. There are few countries, on the other hand, where officialdom generally is as honest and helpful as the Norwegian, especially towards Britons. Thus, there is no doubt but that a foreign industrialist wishing to establish himself in Norway, even if he may be let in for some difficult legal bargaining at the beginning, can in the end secure for himself a fair deal.

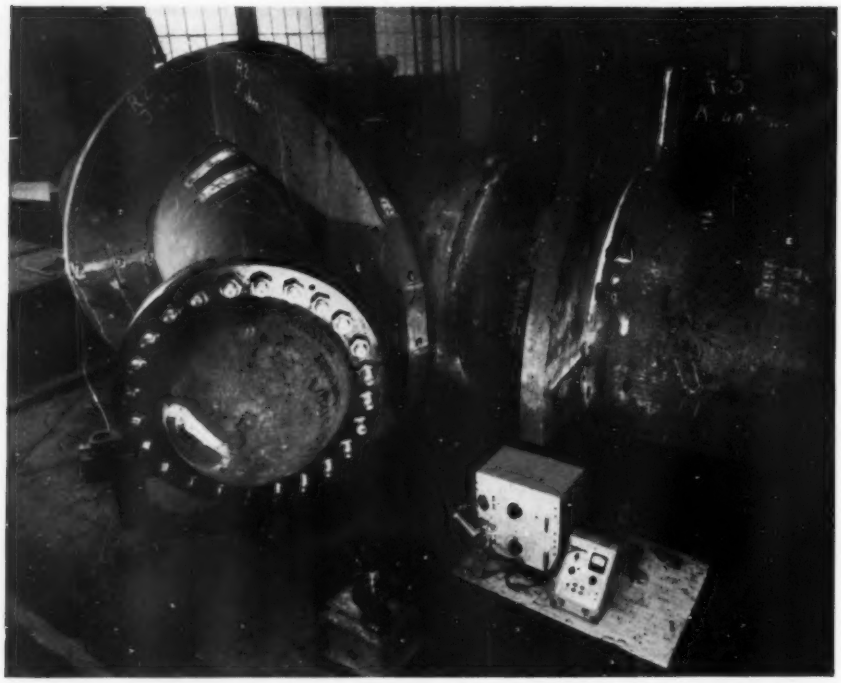


Fig. 1. Stress measurements during hydraulic pressure test on the Lünersee distributor

High Pressure Penstocks

The authors, who are with Sulzer Brothers, Winterthur, Switzerland, have carried out many tests and investigations on the construction of high pressure penstocks and pressure shafts. In this article they list some of the methods used for the fabrication of these penstocks for several hydro-electric schemes in which their firm participated

By W. MÜLLER and K. BRANDLE

IN an effort to improve the construction of penstocks and pressure shafts, the search for new materials has resulted in the exhaustive testing of new types of steels to determine whether they are suitable for penstock construction. Extensive fabrication trials have been carried out with heat-treated steel plates having tensile strengths of 40 to 50 tons per sq. in. and yield points between 30 and 45 tons per sq. in. Very satisfactory results have been obtained and they are now widely used. Of these new materials used, the T-1 steel is notable as its properties obviate unduly thick penstock walls. These properties are as follows:

Tensile strength ...	47 tons per sq. in. min.
Yield point	40 tons per sq. in. min.
Elongation ($L=2$ in.)	18% min.
Reduction in area ...	55%
Notch impact strength (Charpy V at 10°F.)	29·5 ft. lb.

In a test to destruction to investigate the steel and welds at fracture on a 4 ft. 5 in. inside diameter pipe, the longitudinal seam fractured at a stress of 44·5 tons per sq. in. The crack showed pronounced characteristics of a ductile fracture and was held up by the highly cohesive parent metal as shown in Fig. 2.

Design and Development

Special flow and design problems are usually encountered when branches of small diameters connect with a large main pipe. This is the case in which the branch pipes lead to turbines with double Pelton wheels. Full-scale model tests were undertaken and the results favoured the use of double branches having a single point of intersection with the main axis of the distributor. This offered favourable flow conditions and could be fitted with lighter stiffening collars. This was proved on the Motec power station, Gongra development, Switzerland, at which water from the penstock had to be distributed to two turbines. The design of the double branch is shown in Fig. 3. Some of the branch pipes were subjected to hydraulic tests during which stress measurements were made usually

Fig. 2. Destructive test on a pipe of T-1 steel showing ductile fracture along a longitudinal weld

by strain gauges, Fig. 1. This was on the distributor in the Lünersee pumped-storage scheme. Measurements at points of maximum stress were taken and from them the actual reactions at the anchor points were calculated.

Various investigations of pipes of natural size, set in concrete and subjected to inside and outside pressures, have confirmed that accuracy can be obtained by methods of calculation to furnish supplementary data on which to base the dimensions of pressure-shaft linings. Flow tests on models have yielded additional information for use in hydraulic calculations. A close study has been made of methods of laying distributors, and static calculations have helped to throw light on conditions at points of fixation. Space requirements and foundations have here been taken into account as well as flow problems and stresses.

Fabrication

Welding methods have been tested and some actually adopted for the manufacture of high-pressure pipe lines where shielded-arc welding proved to be uneconomical for normal work. On the other hand, the performance figures of double-wire welding, which sometimes allows the manual bead to be omitted, have been improved by the use of a double-headed welding unit. Another satisfactory method used was multi-layer welding, whereby the two electrodes were fed from two different power sources connected on to the Scott system. A further contribution to the improvement of welds is the use of an automatic flame-cutting machine for the simultaneous preparation of all four edges of the plate. This also speeds production.

Wall thickness of penstocks and pressure shafts depend largely on the load that can be carried by the surrounding rock. The fabrication of high-strength plates up to $2\frac{5}{8}$ in. thick presents exacting demands on any workshop. Special welding equipment is necessary, as shown in Fig. 4, where the circumferential seam of a 6 ft. 9 in. inside diameter pipe, $2\frac{1}{2}$ in. thick, is being welded by a submerged arc welding process. The arc-air process has almost completely supplanted the pneumatic grooving chisel for removing backing welds, since it reduces noise and saves time. Another advantage of the method is that flaws are clearly revealed when repairs have to be carried out. The use of hardened and drawn steel plate has also made it necessary to introduce special heat-treatment processes.

Inspection

Ultrasonic testing has proved to be a very useful addition to non-destructive weld-testing methods. The testing system should permit faults of all kinds of weld or parent metal to be located speedily and with great accuracy. Extensive experiment and practical trials have shown that this method of weld testing is of the greatest value both in the shops and in the field. It has proved in many instances to be severer and more accurate than X-ray or gamma-ray inspection. A radiograph of the immediate flaw area can always be made when a record of the findings is required. Hence it is a more effective method of checking welds than the hydraulic pressure test, particularly

Fig. 3. Double branch pipe for Motec distributor of $2\frac{3}{16}$ in. wall thickness. Main inside diameter 4 ft. 11 in., branch inside diameter 2 ft.

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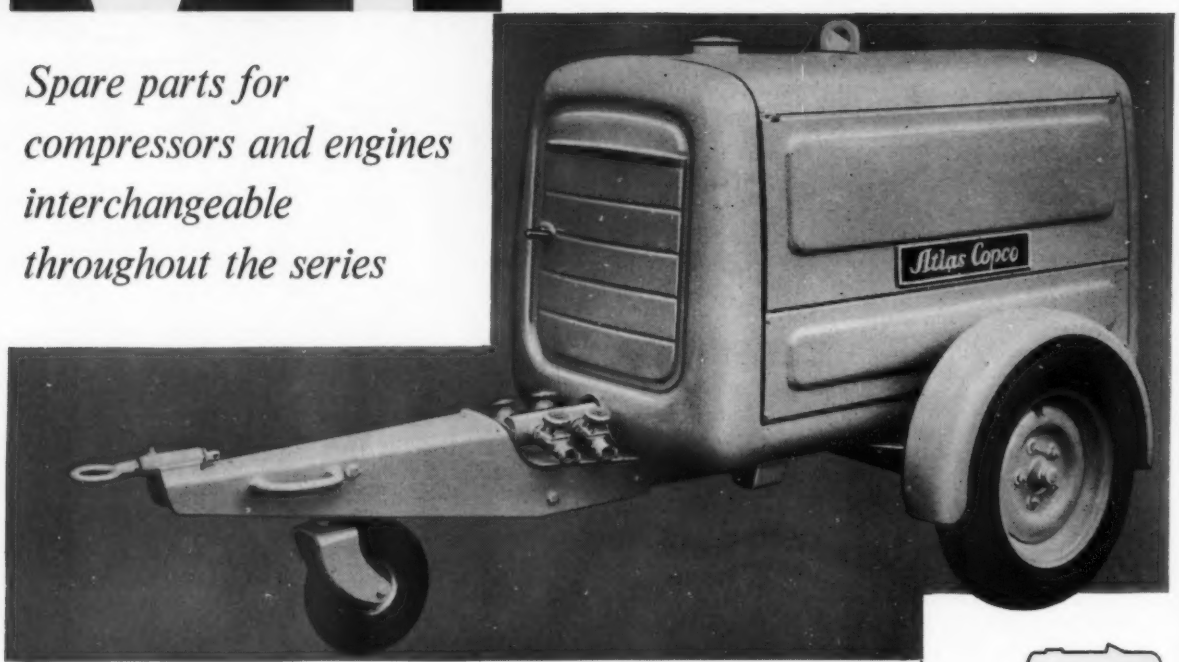

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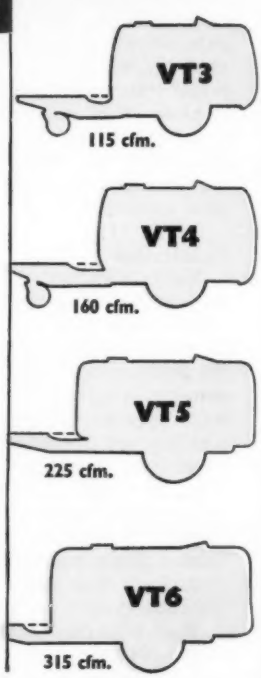

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with thick-walled pipes. While it may be argued that the pressure test also checks the quality of the parent metal there are today far better methods available, and there can be no doubt that the high test pressures only aggravate any internal flaws which may be present. However, this does not mean that the hydraulic pressure test may not continue to be useful for the inspection of special designs. It is worthy of note that a number of steelworks and rolling mills have been persuaded to admit the ultrasonic test for the acceptance of their plates. The latter are inspected singly and are divided for the purpose into a number of narrow sections.

For the owners and manufacturers of high-pressure pipe lines it is reassuring to have improved methods at their disposal for testing the quality of materials and workmanship. Yet, however efficient such methods may be, they can never be a substitute for reliability on the part of the personnel. It is this reliability that justifies the confidence of the purchaser in the good name and conscientiousness of the suppliers, who in their turn must make all provisions for the recruiting and training of highly-skilled workers.

Erection

As the dimensions of penstocks, pressure-shaft and surge-tank linings increase, more automatic welders are necessary on site to enable the pipe shells to be assembled economically. The "Prepact" process for concreting-in pressure-shaft linings has brought major changes in field work. The pipes can now be erected without any interruptions or waiting periods. The use of high-frequency emery grinding machines has proved a success for erection work, particularly in pressure shafts, and makes the installation of compressed-air plant unnecessary. There is no danger whatever from the low voltages employed.

Fig. 4. Automatic circumferential welding on Lünersee pressure shaft 6 ft. 9 in. inside diameter, $2\frac{9}{16}$ in. wall thickness

Automatic Painting of Transformer Radiators

The painting of tubular cooling radiators for power transformers has always presented a difficult problem. To obtain good protection, three even coats covering the entire surface are necessary, but due to the close spacing of the tubes it is extremely difficult to apply very even coats with either brush or spray gun. Dip painting is therefore the only really suitable method. Owing to the large weight and size of such radiators it is not practical to dip the complete radiators, and hence the painting of individual units before assembly appears to be the most logical procedure.

A large Belgian manufacturer of electrical equipment where these radiators are made has recently put an automatic painting installation into service which dips, dries and temporarily stores radiator units by means of a monorail transporter. When ready for painting, eight units are suspended from consecutive carriages by chains, and after an electromagnetically controlled carriage stop has been released, the carriages are moved by a driving chain running along the side of the monorail. The radiators are protected with glycero-phtalic resin base paint by immersion in three consecutive baths, and the application of each one of the three coats calls for four operations mentioned below.

Dipping: This is the first of the operations, where the transformer radiator is lowered into the bath slowly to avoid the formation of air bubbles. The bath is continuously stirred by means of pumps and the viscosity is closely controlled.

Draining: This operation, which calls for two periods of ± 7 minutes, presents no special features, apart from the final drop-removing operation, which eliminates the bead formation which follows ordinary draining. An absorbent roller, controlled by the withdrawal from the bath, removes the last drops immediately before the radiator passes on to the next stage, the drying oven.

Drying: Special infra-red ovens are moved on rails perpendicular to the chain so that they envelope the radiator, the movement of the chain being automatically locked. Temperature control is by a number of thermocouples, depending on the size of the radiator and the heating time is controlled by a time switch.

Cooling: The last of the operations in which the radiators are cooled by fans to reduce their temperature to a value suitable for the next application of paint.

It should be noted that there are several interlocks and safety mechanisms incorporated in the course of the various operations. If the chain is stopped during an operation by one of these interlocks or by means of the stop bush-button, the complete cycle is recommenced, as if the operation in progress had never been started, thus eliminating all possibility of defects and rejects.

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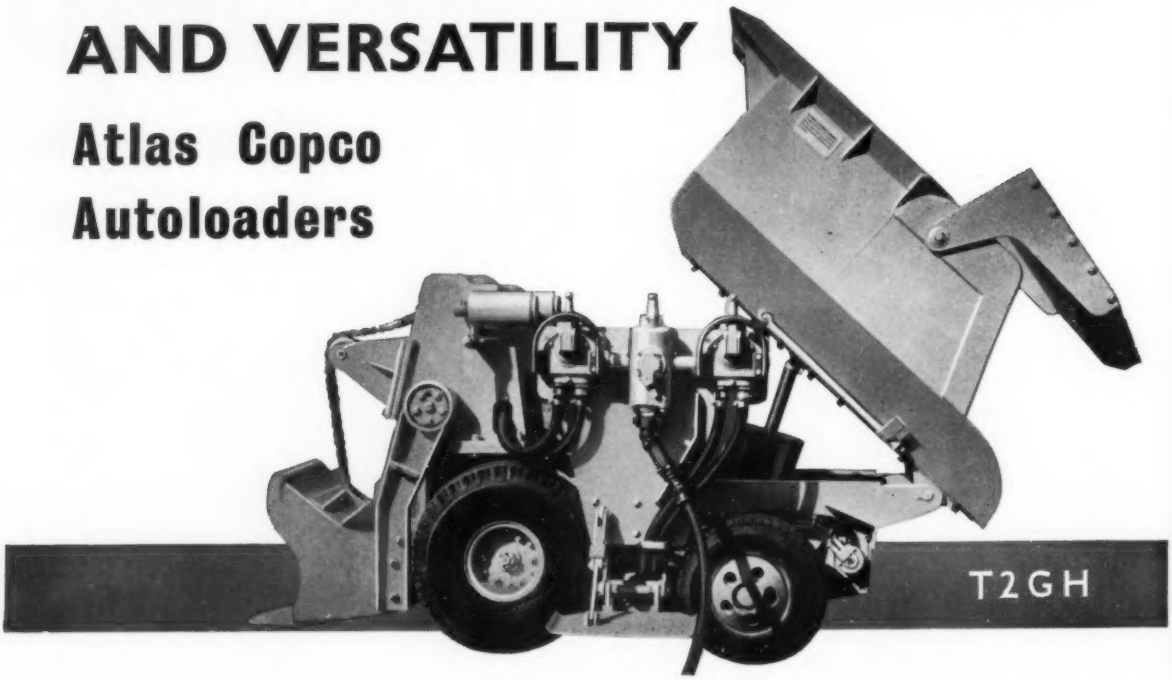

Operated by one man. The complete work cycle — mucking, transport and dumping can be carried out by one man. This reduces labour costs considerably.

Independent of track. Owing to the fact that the autoloader is not rail bound it has an unlimited loading width. Mucking can be carried out just as easily in narrow drifts as in large underground excavations. In addition costs for track laying are eliminated.

Low maintenance costs. Rubber tyres reduce stresses on the machine resulting in lower maintenance costs. The tyre costs per ton loaded vary with working conditions but generally these are extremely low.

Another advantage of pneumatic tyres is that the loader can run over the air hose without the least risk of hose breakages.

High capacity. The capacity is dependent on the distance between the loading and dumping sites, but for instance, with a haulage distance of 70 ft., capacities of up to 55 cu. yds. of material per hour have been obtained.

Many ranges of application. Being independent of tracks the machine can operate over larger areas than track-bound loaders. It can be dismantled quickly and easily if shaft dimensions make transport difficult.

This machine is available in two versions, T2G and T2GH. T2GH has a higher discharge height and is designed especially for dumping on conveyor belts.

Atlas Copco autoloaders are used throughout the world in various ranges of application such as cut-and-fill-stoping in ore mines, seam drifts in coal mines and for loading operations at the surface.

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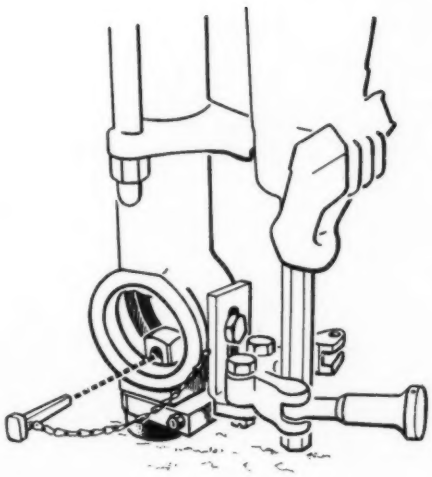


Fig. 1

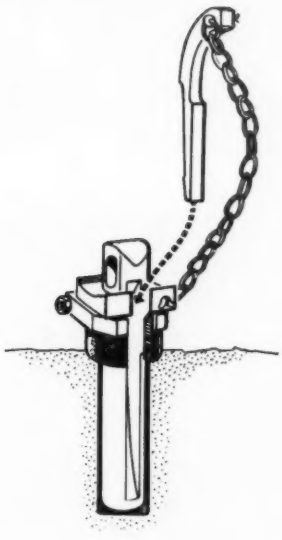


Fig. 2

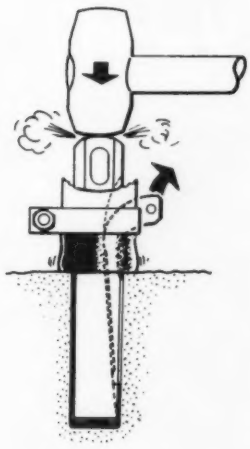


Fig. 3

ATLAS COPCO have recently introduced a "Bencher" which is designed to replace hand-held machines for bench drilling in such operations as shaft sinking, road work, and quarrying, and to act as a complement to wagon drills when the terrain makes transport difficult, or on small-scale projects where it does not pay to employ larger or more expensive equipment. The Bencher has been designed for use in combination with the Atlas Copco "Lion" high-capacity rock drill (see WATER POWER, April 1958). The feed length is 5 ft. 11 in. (1·8 m.) and it is adapted for 5 ft. 3 in. (1·6 m.) interval drill steels. The 5 ft. 3 in. (1·6 m.) intervals between the steel changes give one man opportunity to handle two machines at the same time. When drilling holes exceeding 30 ft. (10 m.) in length, 1 in. extension drill-steel equipment should be used.

The equipment consists of three main parts: Feeder, anchor bolt, and rock drill. The feed movement is transmitted through two tie-rods connected to a double-acting piston rod which travels in an air cylinder. The cylinder has a bifurcated ring at the bottom which can be attached to the anchor bolt to form a knuckle joint (Fig. 1). The square collar of the anchor bolt has a concave seat to accommodate the cylinder ring, and a chained wedge when inserted through the eye in the anchor-bolt head forms the knuckle joint. The rock drill is hung on the two tie-rods by the bracket normally used for the pusher leg. A drill-steel holder attached to the ringed end of the cylinder holds the drill steel steady when collaring. Suitable air feed pressure and direction of feed are obtained by means of a reducing valve at the top of the feed cylinder. The grooved anchor bolt body is inserted in the drill hole and secured by driving down a wedge in the groove (Fig. 2). The bolt has a rubber buffer to prevent it from entering too deep, which permits the bolt to be released by just tapping with a hammer (Fig. 3).

Under normal working conditions one man can handle two machines simultaneously. The working

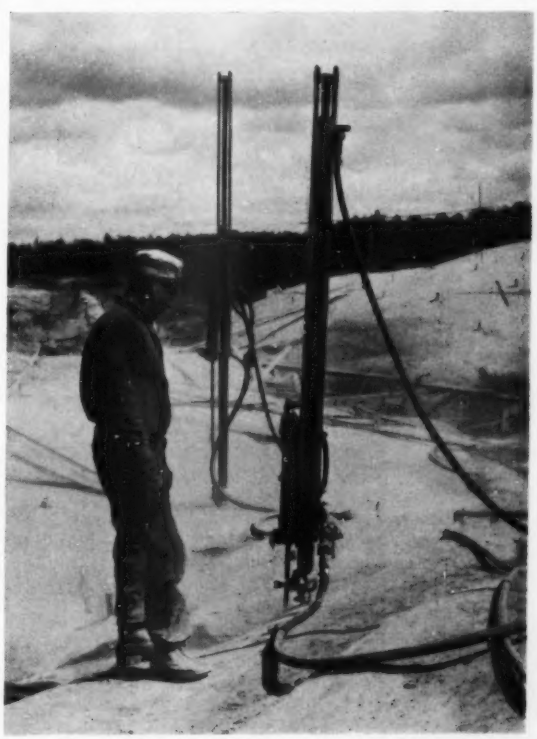
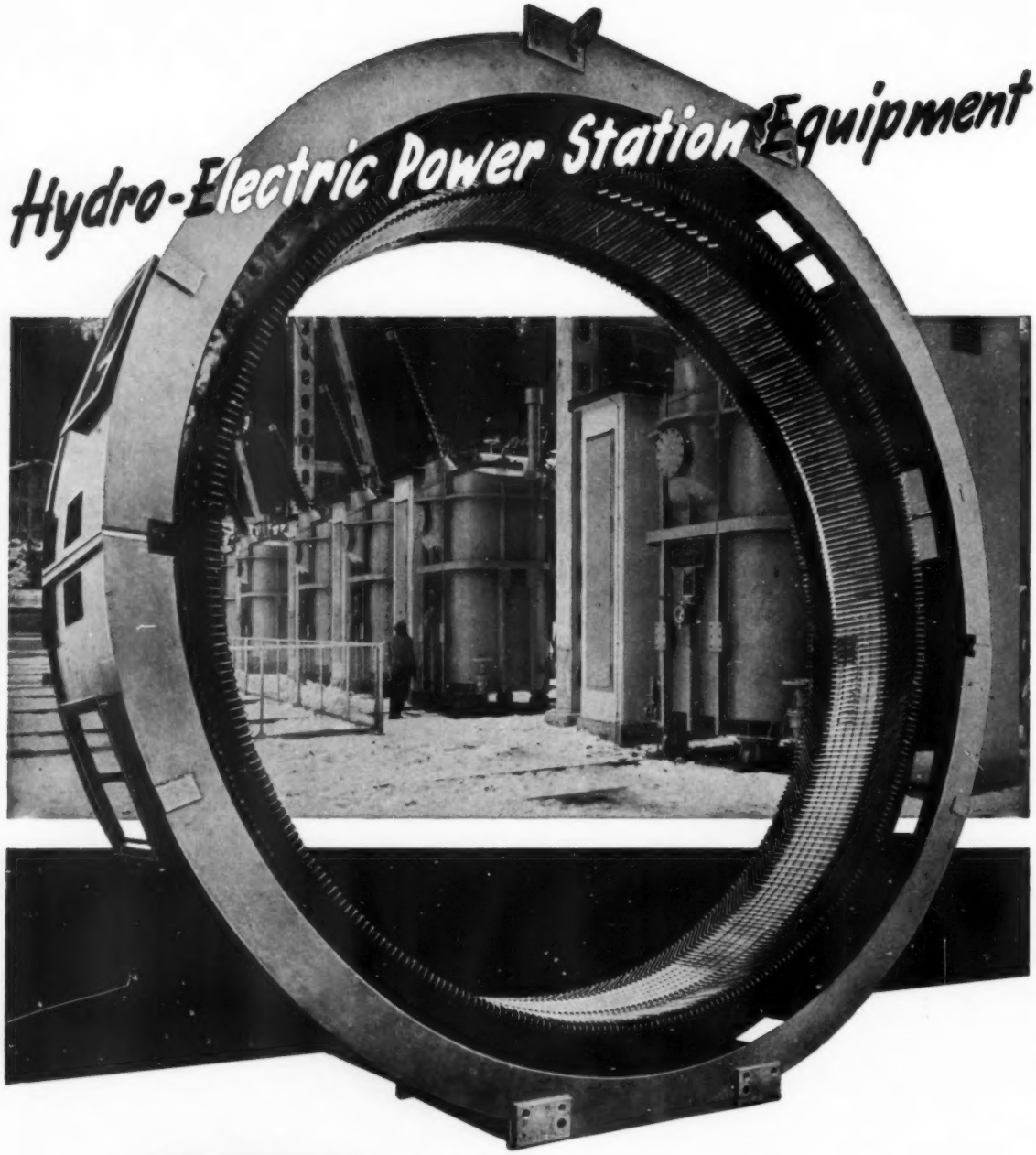


Fig. 4. Atlas Copco bencher in operation

Hydro-Electric Power Station Equipment



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procedure for operating the machine is as follows:

Two anchor bolt holes, about 8 in. (20 cm.) in depth, are drilled with a hand-held rock drill. Anchor bolts and wedges are then placed in the holes and driven tight. Two benchers are placed with their ringed ends on the anchor-bolt heads, the chained wedges inserted and the rock drills started. Additional anchor oolt holes can be drilled and the bolts secured while these two rock drills are operating, thus eliminating waiting time, but if terrain conditions are difficult it may be expedient to drill all the bolt holes before the actual bench drilling operation begins. It is a simple matter to move the machine from one anchor bolt to the next by tapping out the chained wedge to release the ringed end. The complete moving procedure can be carried out in two minutes.

The following advantages are claimed for the Bencher:

1. The compressed-air supply is used for both the drilling and feed pressure. This is not so with the majority of similar machines, as the feed is often gravitational by means of weights. Drill-steel change on such machines requires hand-cranking, which is a time-consuming operation. Drill-steel change with the Bencher takes only 30 sec.

2. High-capacity machines can be used and a high feed pressure maintained, giving this equipment a clear advantage over that of hand-held machines for bench drilling. Furthermore, as it is possible for one man to operate two machines simultaneously, results can be attained which were hitherto deemed impossible. Drilling for blasting in Sweden recently, one man attained a total of 250 yards (228 m.) in one shift—possibly a world record for bench drilling with rock drills in this weight class.

3. It is easy to set the feed pressure for the type of rock to be drilled. This is more difficult with weight-loaded feeds.

4. The Bencher can be set at different angles with the knuckle joint.

5. When changing drill steels the Bencher can be used to raise the rock drill and the drill steel. This spares the operator effort.

ATLAS COPCO BENCHER DATA

Weight without anchor bolt (excluding rock drill) ...	89 lb.	(40·5 kg.)
Overall length, contracted	7 ft. 4 in.	(2,225 mm.)
Overall length, extended ...	13 ft. 2½ in.	(4,025 mm.)
Effective feed length ...	5 ft. 11 in.	(1,800 mm.)
Piston diameter	2⅝ in.	(67 mm.)

Abstracts from the World Technical Press

The Field Laboratory at Göschenalp Dam

The field laboratory attached to the construction site of the Göschenalp dam and the investigations it carries out are described in detail. The dam consists of an impervious core of clay 150 m. in maximum height, inserted between transition fills, the upstream and downstream slopes of which are protected by dumped rock. The crest of the dam, 550 m. in length, lies 1,797 m. above sea level, and the volume of fill material placed is 9 million cu. m. The tasks of the laboratory, which varied as planning and, subsequently, actual construction work progressed, can be divided into five groups: (a) preliminary investigations at the dam site and at fill-material borrows; (b) detail investigations and borings, especially in the region of the upstream toe of the dam; (c) large-scale tests to determine the best method of placing the various kinds of fill material; (d) control of construction work; (e) close watch of the dam body during construction and after it had been put into service. The spot selected for the laboratory, about 200 m. from the dam bank on the left-hand slope of the valley, enables the staff to reach easily and promptly any spot of the building site. It is easily accessible to vehicles, well protected from snow slips, and ensures good supervision of the building site. Of the 52 members of the staff no fewer than 44 are fully occupied with material control. A full range of testing equipment for all the tests occurring in earth-dam building practice is available. Two 5 kW furnaces can dry 120 to 150 kg. of material at a temperature of 105°C. in three to four hours—10 kg. of material being required for unit weight determination. A single furnace can cope with 20 samples under normal conditions, while the second furnace stands by as an indispensable reserve in case of stoppages or for complementary tests. In fact, these complementary tests frequently prove necessary during the first construction years, since, in the course of the extraction and preparation of the fill material, there is always a recurrence of difficult problems which require quick solution. Special attention is paid to grain-size distribution as well as to compaction and permeability tests. Two jeeps and trailers are permanently available, one for the transport of samples and implements, the other for conveying the head of the laboratory to any spot of the building site where his presence may be required. Adequate provision is made for water and electricity supply, and there are taps at all working points of the laboratory. About 34 kW of power is available; 17 kW for heating and lighting, and the rest for the furnaces and testing equipment. (Dipl. Ing. H. Zeindler, Elektro-Watt, Zurich, *Schweizerische Bauzeitung*, Vol. 77, No. 33, August 13, 1959, p. 53, 5 pp., 5 ff.)

Storage Pumps

In this abundantly illustrated article, the author reviews the problems arising at the designing stage of storage pumps, especially units operating in conjunction with generating sets. Special stress is laid on determining the correct speed of the set and the permissible suction head of the pump with a view to avoiding cavitation. The aeration of turbine and pump is also discussed for the three modes of operation occurring in pumped-storage plants: generating, pumping, and using the motor-generator for improving the power factor of the network. Finally, the author deals with the protection of storage pumping sets from non-stationary surges in the piping and from reversed rotation when the motor-generator is suddenly disconnected from the network. Czechoslovak

How much sludge will a Sludge Pump pump?

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engineering industry is obviously devoting great attention to storage pumps, and is now endeavouring to improve their degree of efficiency. The oldest pumped storage system in the country, commissioned in 1945 at Stěchovice, upstream from Prague achieved 60% efficiency while an improvement of 5% is expected from the pumping-generating plant at Amalienhöhe, Eastern Germany, for which the mechanical equipment is being delivered from Czechoslovakia. (Dipl. Eng. Josef Hušek, *Czechoslovak Heavy Industry*, Vol. 1959, No. 8, p. 21, 8 pp., 13 ff.)

NOTE: The above mentioned journal, printed in English, also contains a short article on small generating sets intended for midget hydroplants and driven by either Francis, Kaplan or Pelton turbines. A comprehensive diagram for the selection of small turbines is included. (Dipl. Ing. Boris Kratochvil, pp. 29/31, 10 ff.)

Grouting Joints at Grande Dixence Dam

One of the main features of this unusually large gravity structure is that it is being built by stages. Following normal practice, the dam has been divided into a number of blocks fitted with spigots which transmit stresses through the longitudinal joints while, in the case of transversal joints, they ensure the interdependence of neighbouring blocks. To speed up the cooling and subsequent contraction of the concrete blocks, artificial cooling was applied to enable the joints to be grouted before impounding reached their level. The cooling system used consisted of serpentines of piping laid flat on each 3·2 m. lift of concrete, through which cold water was circulated. This piping remains, of course, embedded in the concrete. When the concrete reaches a mean temperature of 5°C. (this temperature is generally reached in the spring following placing), the joints involved are grouted. The surface of contact between two blocks constitutes a 16 m. high panel which may vary in length between 16 m. (longitudinal joints) and 40 m. Two serpentines fitted one above the other—one a standby—similar to the cooling systems extend over each panel. Nests of eight 3 mm. holes, spaced at 3 m. in transversal and 1·5 m. in longitudinal joints, are provided in the pipes. Grouting is checked by means of a collecting groove fitted at the top end of each panel. When grout emerges from the collecting groove in exactly the same condition as when injected, the collecting groove is shut off and the panel affected is put under a pressure not exceeding 10 kg. per sq. cm. except at the lowest parts of the dam, where it has been increased up to 30 kg. per sq. cm. Once the selected pressure is reached, it is maintained for 10 minutes. Grouting is effected in six operations: (1) Flushing and testing the grouting pipes; (2) thorough cleaning of the panel, lasting at least 20 minutes, by means of the lower system of pipes; (3) filling the standby piping with water, and maintaining in it a slight circulation of water so as to keep the holes open while the panel is being grouted; (4) maintaining in any adjacent transversal joint awaiting grouting a water pressure equal to half the grouting pressure; (5) actual grouting, the grout simply consisting of water and cement mixed in the proportion of 0·7 to 1·0; (6) flushing the piping and top collecting grooves. By the end of 1958, 430 panels aggregating 105,594 sq. m. had been grouted; this means an average of 246 sq. m. per panel. It has been ascertained that wing panels adjacent to the rock abutments absorb substantially more grout than other panels. Regrouting of transversal joints attempted during the spring of 1959 by means of the bottom network of piping proved impossible even after a previous injection of water at the rate of 2 to 3 lit. per min. On the other hand, regrouting through the top collecting groove was found feasible in 40 instances out of 100. (J. Torrione, *Schweizerische Bauzeitung*, Vol. 77, No. 39, September 24, 1959, pp. 929/931, 4 ff.)

Lower-Durance Development

The Lower Durance, the stretch of the river downstream of its confluence with the Verdon, is to be harnessed to power generation by a canal diversion discharging 350 cu. m. per sec. and operating a chain of five plants: Jouques, close to the Verdon confluence and now nearing completion, and Saint-Estève-Jansonon, on which work was started early in 1959, both on the section of the canal lateral to the river; Mallemont, Salon and Saint-Chamas, to be set up on the lower reach of the canal after its sharp bend southward downstream from Mallemont. This article deals exclusively with the installations of the Jouques stage which comprise the overflow-type Cadarache dam, the supply system which consists of an open channel and of a pressure tunnel, the power house and the tailrace. The five bays of the Cadarache dam, 25 by 6·5 m. are controlled by tainter gates, two of which are fitted with 1·75 m. high flap shutters. The abutments and wing-walls are constituted by caisson-type walls founded on the rock and filled with compacted alluvium. The streamlined piers, standing 24 m. high above foundations, are 30 m. long, including 1·30 m. overhanging on the upstream side. The piers are 5 m. thick with the exception of pier No. 1 on the left bank, which consists of two 3·5 m. thick half-piers enclosing a sand-trap—a 5·0 m. diameter ferro-concrete pipe. The inlet to the sand-trap, which extends almost 100 m. upstream from the dam and faces the intake, which consists of a rock-founded sill 94 m. long laid perpendicular to the dam, and has a fine screen 375 sq. m. in wetted surface and is fitted with a trashrack. The open channel of the supply system, 7·2 km. long, is trapezoidal in cross-section, 8·6 m. wide at the bottom and has a gradient of 0·2 m. per km. It is concrete lined throughout, 15 cm. thick at the floor and 20 cm. on the slopes. The pressure tunnel, sloping 1 m. per km., is also concrete lined throughout, and has a free cross-section of 78·30 sq. m. At its upstream end there is a difference of level of 12·5 m. between its invert and the floor of the open channel, and the transition between the cross-section of the channel and that of the tunnel is effected by a steep forebay fitted with an inclined trashrack having its bars 10 cm. apart. At its downstream end the tunnel divides into two branches, one, of equal cross-section to the tunnel, connects with the penstocks through a manifold, the other, of 6 m. inside diameter, leads to the gates of the bypass channel provided between the power-house block and the right bank. The purpose of this bypass is to ensure the supply of water power from the tailrace of the upstream plant to the St. Estève and Mallemont stages in the event of a stoppage at the Jouques plant. Each

of the three underground ferro-concrete-lined penstocks 6 m. in diameter, leads to a cylindrical surge chamber 8 m. in diameter, also ferro-concrete lined, and any overflow from the surge chambers collects in tanks 8 m. wide by 10 m. high, which empty into the bypass channel. The power-house block is of the flat-deck type, each turbine pit being covered by a sliding roof so that the equipment can easily be handled by the gantry crane travelling on the deck. The three 20·8 MW Kaplan turbines, which operate at 187·5 r.p.m., and are fed from the penstocks by underground reinforced-concrete conduits 4·5 m. by 6 m. in cross-section by 27 m. in length. The casings and draft tubes are also of reinforced concrete. The alternators have a rated capacity of 26 MVA at 10·5 kV. The machine hall is 80 m. long by 9 m. wide and 11·5 m. high; its full width is occupied by the generating sets which leave lengthwise 7 m. spaces for the governors and other ancillary equipment. The hall extends on the left bank to include an erection bay 33 m. by 9 m. A service travelling crane which runs inside the hall can handle all necessary loads. The site of the power-house block was selected with a view to providing a rock foundation for the generating sets, but this confronted the contractors with difficult problems. In fact, the foundation rock dips sharply and it was necessary literally to squeeze the building into the calcareous rock and to excavate to fair depth. There were further difficulties, partly because of abundant outbreaks of water and also because of the deficient behaviour of the rock, which had to be cut vertically to a considerable depth. The 3 km. tailrace constitutes the upstream end of the 27·5 km. canal section which will power the St. Estèphe plant. Its function in relation to the Jouques plant is, while appreciably increasing its operating head, to enable the tailwater to be returned temporarily to the river above the highest flood level. The article concludes with an account of the work entailed in the relocation of two highway sections totalling 7·8 km. This was caused by the fact that both the tailrace and the supply canal had to be set up in part on the actual course of these highways. Four bridges had to be built to re-establish communications. (J. L. Pichon, *Construction*, Vol. XIV; No. 4, April 1959, p. 108; No. 5, May 1959, p. 146; 16 pp., 21 ff.)

NOTE. A comprehensive survey of the general Durance development appeared in the April to July issues of WATER POWER, 1957. An article on this development is also included in *Technique de l'Eau*, Vol. 13, No. 153, November 15, 1959, p. 27, 4 pp., 5 ff.

Flow Studies

In a briefly described report on the experiments carried out by the authors on the flow of water in a tube at high rates of swirl, the test apparatus consisted of a Perspex tube 62 in. long, 2 in. diameter, fitted symmetrically in an open steel tank 1 ft. wide, 2 ft. deep, which was divided by two vertical diaphragms into a 4 ft. long middle compartment and two 2 ft. long end compartments connected externally. The 4½ in. middle stretch of the tube formed a perforated revolving drum. Two constant-level tanks were provided both with long overflow weirs, one maintaining a steady level in the end compartments, the other—fixed well above the main tank—feeding the middle compartment. Water was circulated through the system by a pump. The motion inside a single- and double-ended swirl chamber was simulated by rotating the drum and admitting water under gravity through its numerous holes. The swirling velocity at entrance could thus be measured, and it could be changed without altering the discharge. With various obstructions in the fixed part of the tube, the flow pattern was examined by means of injected colour. The reversed axial flow, which had been discovered in previous experiments on large nozzles, was again found. At higher swirls, a region occurred which consisted of three streams moving towards the orifice of the obstruction along the axis close to the wall and at about half radius, with two intermediate streams in the opposite direction. Numerical results are presented in dimensionless form. (A. M. Binnie and M. Y. M. Kamel, Engineering Laboratory, Cambridge, *La Houille Blanche*, Vol. 14, No. 3, May-June 1959, p. 348, 13 pp., 6 ff).

NOTE: The English text of this report is given together with the French translation.

Cavitation Phenomena

A paper presented at the 28th Annual Meeting of the Research Committee held at Srinagar, India, in June 1958, dealt with the investigations carried out on all aspects of cavitation phenomena. The results of theoretical and experimental researches regarding the mechanics and mechanism of the various types of cavitation were discussed. A description of the techniques applied to the study of the phenomena was also given and the paper dealt with the limitations of applying laboratory results to prototypes. A final paragraph was devoted to the prevention of cavitation in a few hydraulic machines and structures. An abundant bibliography was appended. (N.S. Govinda Rao, *Irrigation and Power*, Vol. 15, No. 4, October 1958, p. 514, 16 pp., 11 ff.).

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Announcements for this column can be accepted up to the 8th of the month for the following month's issue. The charges are fourpence per word with a minimum of 10s. Box No. facilities 2s. 6d. extra. In order to avoid accountancy it would be appreciated if instructions to insert were accompanied with remittance.

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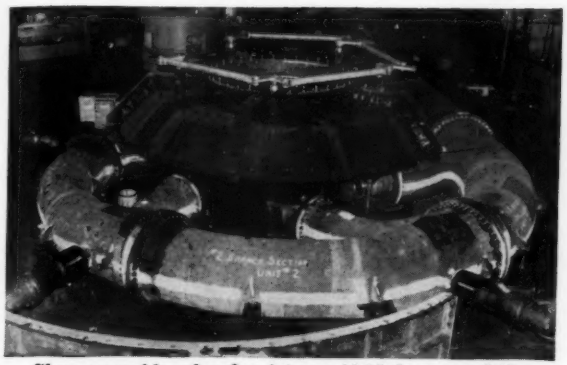
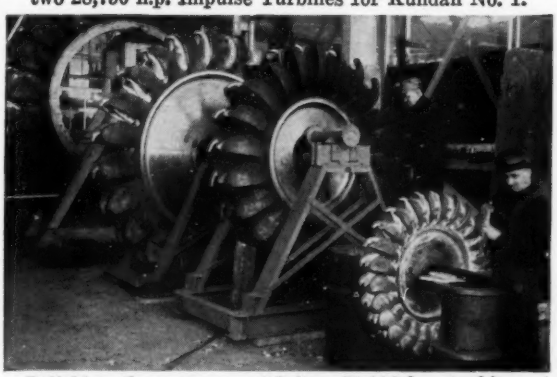
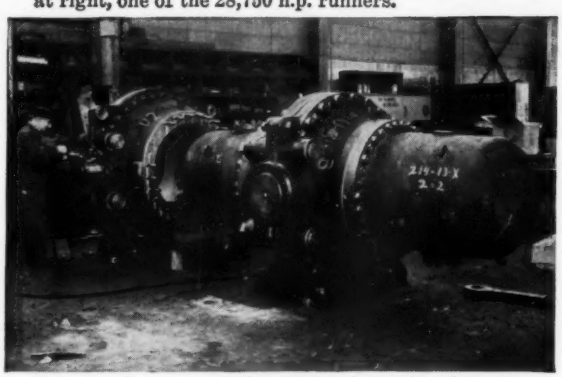


Shop assembly of a five-jet manifold for one of the two 28,750 h.p. Impulse Turbines for Kundah No. 1.



Polishing the runners—at left, a 50,000 h.p. turbine, at right, one of the 28,750 h.p. runners.



Shop-testing one of the 2'6" spherical valves for Kundah No. 2 at a pressure of 2,140 psi.

"IT MAKES LIGHT WHERE THERE WAS DARK."

Rangaboyan said that. He is foreman of a crew pouring concrete for the Kundah Hydro-Electric Project in Madras.

It would probably not mean much to Rangaboyan if you told him that there are two Dominion Impulse Turbines at Kundah No. 1, developing 28,750 h.p. each under a head of 1,186 feet, and four turbines at Kundah No. 2 producing 50,000 h.p. each under 2,470 feet, and that Dominion Spherical Valves can shut off each turbine and hold back this enormous water pressure.

He might agree politely to your statement that the Kundah Development is one of the largest Colombo Plan Projects, and that its total cost will amount to $70,000,000.

And he wouldn't know what you were talking about when you told him that Kundah's total annual capacity of about 8 million KWH is enough to increase the present per capita consumption in Madras by 50%—from 36 KWH to just over 50 KWH.

Rangaboyan, you see, cannot read or write. Yet he said it all with simple directness—"it makes light where there was dark".

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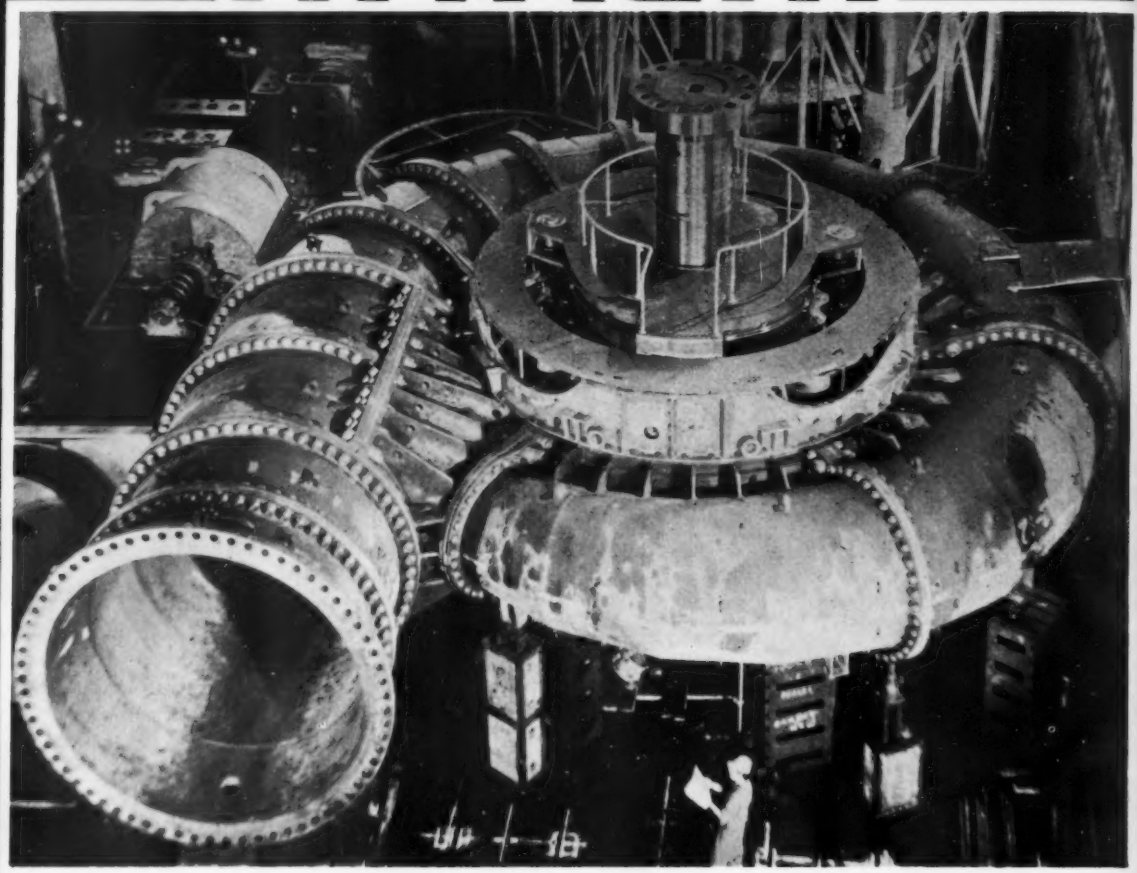
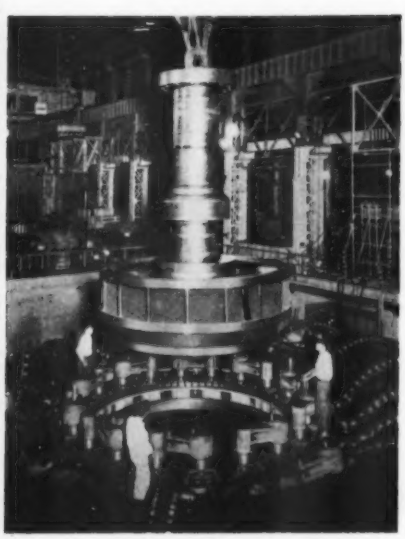


Another big Francis Turbine by Hitachi



The completion of yet another big Hitachi job was recently marked by the successful factory tests of a 137,500 kW Francis Turbine. This is the first of a pair to be built, together with two 125,000 kVA generators for the Miboro Power Station in Central Japan.

This vertical-shaft Francis Turbine is specified for a speed of 225 r.p.m., a maximum effective head of 200 m. and 76.6 m^3/sec. water flow, making it one of the largest units of its kind in the world. Its runner has a maximum diameter of 3.7 m. and the main shaft a diameter of 95cm. The spiral casing, which was constructed in 13 sections to facilitate transportation to the site, has an inlet diameter of 3.35 m. and an outer diameter of 11.2 m.

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VOITH

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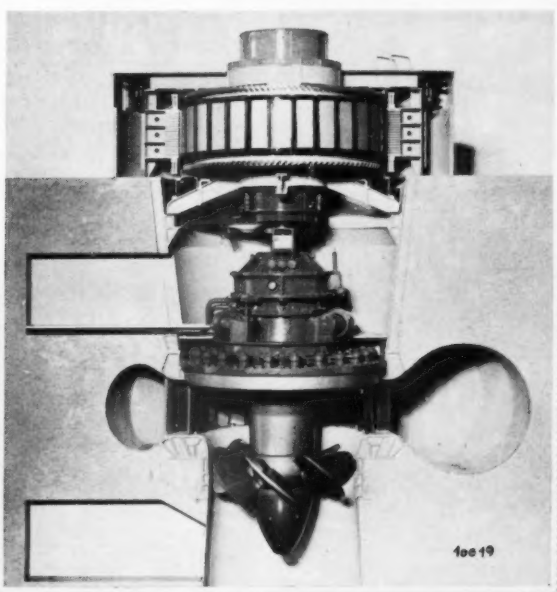
The outlines at the left are those of one of the two 90,000 b.h.p. Kaplan turbines in manufacture in our workshops for operation under 164 ft. head in the Três Marias Hydro-Electric Power Station, Brazil (descriptive article in this issue).

The 8-blade runner has a diameter of 15 ft. These turbines are of typical Voith design embodying all-welded spiral case, all-welded head cover, all-welded gate operating ring, annular gate-servomotors, with the thrust bearing on top of the head cover and the oil supply to the runner servomotor through the upper main-shaft guide bearing.

These turbines are very similar to the 33,500 b.h.p. Kaplan turbines operating under a head of 131 ft. in the Rosshaupten Hydro-Electric Power Station. The photo shows the model of the Rosshaupten turbines.



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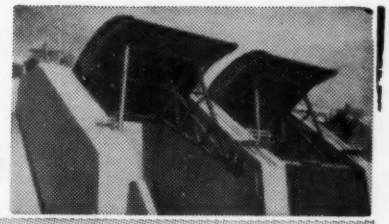

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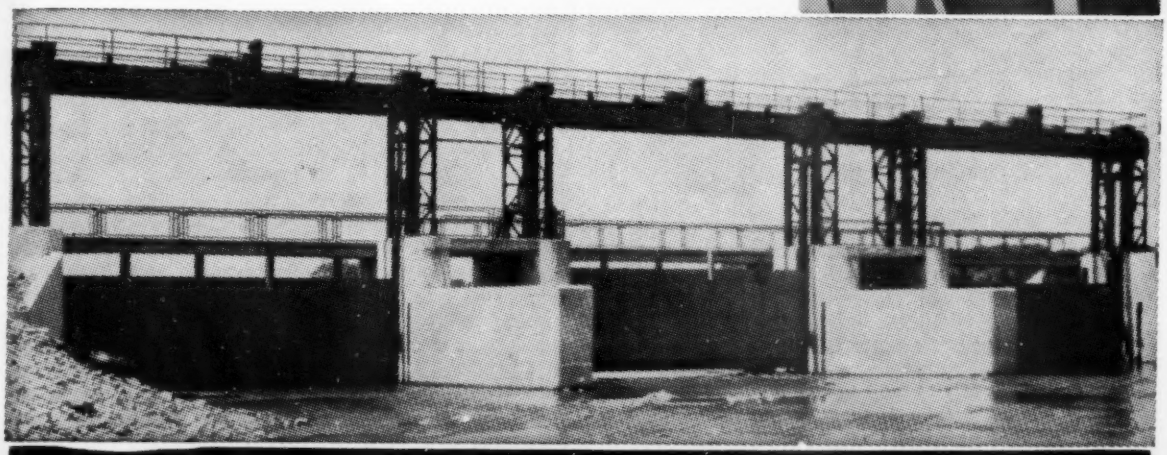

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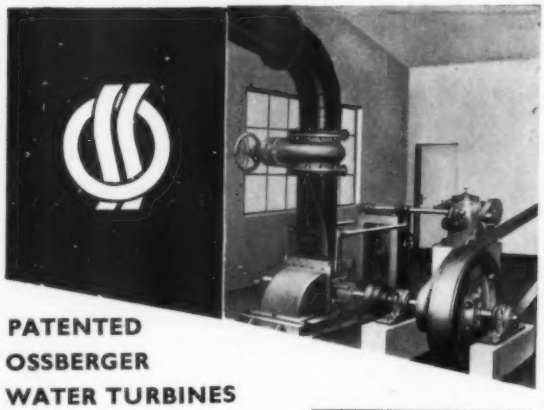

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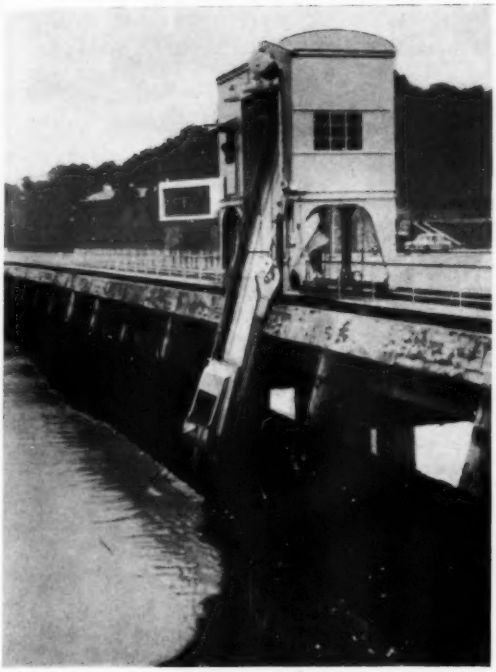

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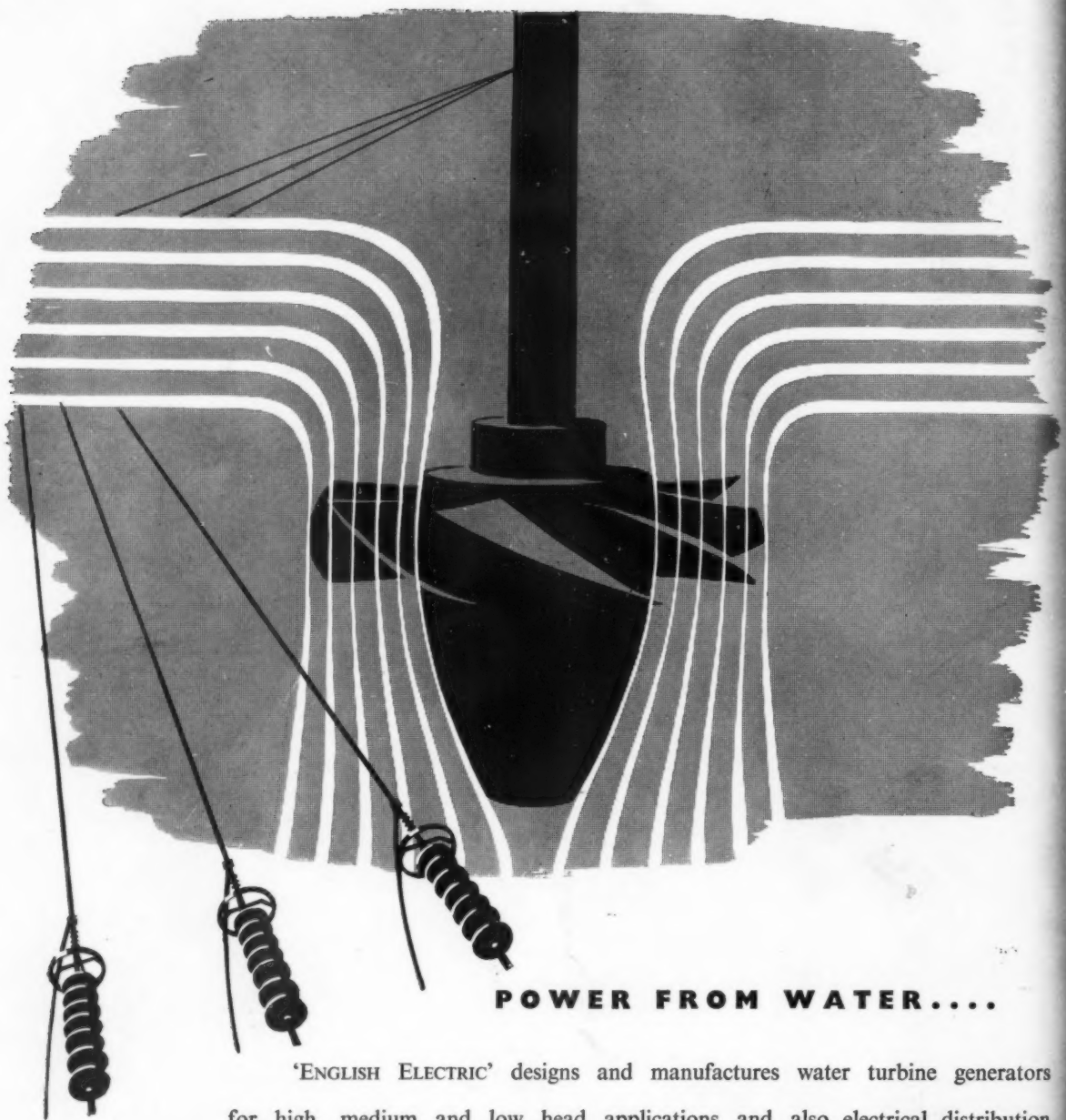

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